SEATTLE PUBLIC UTILITIES
2007 WATER SYSTEM PLAN

IV. DISTRIBUTION

APPENDIX A

DISTRIBUTION SYSTEM ASSETS INVENTORY

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Distribution System Reservoirs					
Reservoir	**Total Capacity (MG)**	**Year Constructed**	**Overflow Elev. (feet)[1]**	**Under-Drain**	**Construction Type**
Covered Reservoirs					
Bitter Lake	21.3	1956/57	509	Yes	Reinforced concrete slab. Hypolon liner and floating cover added in 2001.
Lincoln	12	2004	326	Yes	Reinforced concrete reservoir. Below grade.
Magnolia	5.5	1993/94	330	Yes	Reinforced concrete tank. Part below grade.
View Ridge	2.5	1977/78	276	Yes	Reinforced concrete tank. Below grade.
Beacon[2,3]	50	1911	326	Yes	To be constructed as below-grade reinforced concrete reservoir.
Myrtle[3]	5	1946/47	498	Yes	To be constructed as below-grade reinforced concrete reservoir.
Open Reservoirs					
Roosevelt	50.3	1910	326	Yes	Unreinforced concrete slab. HDPE liner.
Volunteer	20.5	1901	430	No	Unreinforced concrete slab.

Source: Albarracin and Stumpf, July 1999, and Mantchev and Capron, 2006

1. All elevations based on North American Vertical Datum (NAVD).
2. Beacon South has been empty since March 1976; information not shown.
3. Scheduled for demolition and replacement beginning April 2006; data shown for replacements.

Prepared April 2006

Distribution System Pump Stations

Pump Station	Pump #	Manufacturer	Model	Design Flow (gpm)	Head (feet)	Speed (rpm)	Horse-Power	Comments
Bitter Lake	1	Gould	3405	4,000	162	1,775	200	
	2	Gould	3405	4,000	162	1,775	365	Diesel standby use only
	3	Gould	3405	4,000	162	1,775	200	
Broadway	1	Fairbanks Morse	2844C	4,700	245	1,781	400	
	2	Fairbanks Morse	2844A	2,800	237	1,784	250	
	3	Fairbanks Morse	K65226	4,000		1,150	300	
Dayton Ave.	1	De Laval	56064	1,400	110	1,750	50	
	2	MP		100	100	3,450	5	
First Hill[1]	3	Fairbanks Morse	2824C	2,800	180	1,775	200	Computer link with Broadway
	4	Fairbanks Morse	2824C	4,900	190	1,775	350	Pump Station pumps 1 and 2
Green Lake	1	De Laval	98851	900	331	1,750	93	Water Turbine Powered
Interbay	1	Worthington	10 LN 18	3,500	110	1,185	125	Low service
	2	Worthington	8 LA 4	3,500	230	1,785	300	High service
Lincoln	1	Worthington		3,900	117	1,540	125	Water turbine powered
Northgate	1	Allis Chalmers	205-603-502	5,500	182	1,760	300	
	2	Allis Chalmers	205-603-501	5,500	182	1,760	300	
Roosevelt	1	Allis Chalmers	201-052-501	3,000	110	1,760	100	
	2	Allis Chalmers	201-052-501	3,000	110	1,760	100	
Scenic Heights	1	Aurora	411 BF	450	95	1,750	20	
	2	Aurora	411 BF	450	95	1,750	20	
	3	Aurora	411 BF	1,100	100	1,750	40	
	4	Aurora	411 BF	1,100	100	1,750	40	
SW Spokane	1	Allis Chalmers	207-52-510	4,000	290	1,760	400	New starters and transfer switch in
	2	Allis Chalmers	207-52-510	4,000	290	1,760	400	1997; can be powered by diesel gen.
Viewridge	1	Layne		2,500		1,750	100	To 316 zone
	2	Layne		3,500		1,750	350	To 520 zone
Volunteer	1	Allis Chalmers	201-194-502	4,000	108	1,760	125	
	2	Allis Chalmers	201-194-501	4,000	108	1,760	125	
Warren Ave.	1	Allis Chalmers	207-521-510	4,000	265	1,770	350	Can be powered by diesel generator.
	2	Allis Chalmers	207-521-509	4,000	265	1,770	350	
West Seattle	1	Ingersol Rand	10 AFV	4,500	62.3	1,750	100	
	2	Ingersol Rand	11 AFV	4,500	62.3	1,750	100	

Footnote:

(1) First Hill pump station has two pumps, they are labeled 3 and 4. The pumps work in conjunction with pumps 1 and 2 and the Broadway pump station.

Notes:

gpm = gallons per minute

rpm = revolutions per minute

Vert. = vertical

Prepared April 2006

Distribution System Standpipes and Elevated Tanks

Facilities	Capacity (MG)	Year Const.	Base Elev.[1] (feet)	Overflow Elev. (feet)	Diameter (feet)	Tank Height on Riser (feet)	Tank Material	Date of Last Inspection	Interior Coating		Exterior Coating		Seismic Upgrade (or Date Scheduled)
									Type[a]	Date Applied	Type[b]	Date Applied	
Standpipe													
Barton	1.40	1927	277	326	80	-	Riveted Steel	Jan 98	CTE	1960	Lead base	1981	To be determined
Charlestown	1.26	1996	424	498	58	-	Welded Steel	Feb 99	epoxy	1996	epoxy/urethane	1996	Not needed
Queen Anne[6]	2.00	2007	460	530	75	-	Welded Steel	N/A	epoxy	2007	To be determined	2007	N/A
North Trenton	1.19	1932	296	330	92	-	Riveted Steel	Jan 98	Vinyl	1979	Lead base[2]	1990	Not needed
South Trenton	1.19	1932	296	330	92	-	Riveted Steel	Oct 98	Vinyl	1979	Lead base[2]	1990	Not needed
Volunteer Park	0.88	1907	460	530	50	-	Masonry/Riveted Steel	Apr 99	Vinyl	1981	Lead base	1981	To be determined
Woodland Park	1.00	1925	356	430	50	-	Riveted Steel	Oct 98	Vinyl	1984	Lead base	1980	To be determined
Elevated Tanks													
Magnolia Bluff	1.00	1947	369	480	86	25	Welded Steel	Mar 99	epoxy	1988	Zn/Alkyd[3,4]	1988	1993
Maple Leaf	1.00	1949	431	530	84.25	25	Welded and Riveted	Jan 98	epoxy	1988/95	Lead base[5]	1988	2002

Source: Jacobsen, June 1999, and Mantchev 2006.

All elevations based on NAVD 88.

a CTE = Coal Tar Enamel; p-urethane = Monolithic polyurethane lining

b epoxy = NSF epoxy primer and intermediate coats; anc Zn/Alkyd = Zinc yellow primer and silicone alkyd enamel top coat

1. Top of concrete base.
2. Trenton tanks were power tool cleaned and overcoated with an urethane/epoxy/urethane paint system in 1990.
3. Magnolia Bluff was commercially blasted and coated with a non-lead alkyd system. Some lead remains on the tank.
4. 1993 seismic upgrade added all new steel to legs and riser, and coated legs and riser with a non-lead alkyd enamel paint system. The bowls still have the lead based primer as noted.
5. Maple Leaf has some remaining red lead primer then coated with moisture cured urethane primer and top coats.
6. Queen Anne Tanks #1 and #2 scheduled for replacement with single tank in 2007.

Prepared April 2006

Meters by Classification

Classification	Meter Size													
	3/4	1	1-1/2	2	3	4	6	8	10	12	16	20	24	Total
Residential	139,204	15935	1,140	434	1	5	0	2	0	0	0	0	0	156,721
Commercial	6,958	5201	3,413	4387	357	1797	1214	641	25	1	0	0	0	23,994
Key Accounts	461	359	285	654	129	255	284	208	45	15	0	2	0	2,697
Total	146,623	21,495	4,838	5,475	487	2,057	1,498	851	70	16	0	2	0	183,412

Source: Water Meter Count by Billing Size (Run Date 2/21/06); Lanning

Prepared Feburary 2006

SEATTLE PUBLIC UTILITIES
2007 WATER SYSTEM PLAN

IV. DISTRIBUTION

APPENDIX B
SYSTEM DESIGN STANDARDS

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Seattle Public Utilities

System Design Standards

June 2006

This appendix to the *2007 Water System Plan* summarizes standards used by Seattle Public Utilities (SPU) for design or analysis of the water system serving retail customers. These standards are generally the same as those included in the *2001 Water System Plan Update*. The only significant changes are those related to the System Pressure.

1. Average Day, Maximum Day, and Peak Hour Demands

The average day demand values used in the SPU hydraulic network models are based on actual billing records from 2005. To simulate peak hourly demand (PHD) and maximum day demand (MDD) conditions, the 2005 ADD models were set up and calibrated to simulate actual records from the year 1998 peak demand day, July 27, 1998. The 1998 peak day had a total system consumption of 264 million gallons (MG). The PHD peaking factors are taken from the maximum demand hour from the simulation, and the ADD peaking factors are taken from the overall average for that day.

2. Storage Requirements

Hydraulic modeling of various scenarios proved to be an effective way to evaluate storage needs in the complex Seattle system. Scenarios representing peak week conditions, as well as a range of emergency conditions, provided the basis for the analysis. The suite of modeling scenarios provides a benchmark for storage needs of the water system.

3. Fire Flow Rate and Duration

Both the City of Seattle and King County have adopted the International Fire Code (IFC), and the fire flow rates and duration specified in the IFC are used in the analysis of distribution hydraulics and storage requirements.

4. Minimum and Maximum System Pressure

Minimum pressure criteria for new watermains are 30 pounds per square inch (psi) under peak hour demand conditions, and 20 psi when flows are a combination of average maximum day demand and required fire flow. In no case shall pressure at the customers meter be less than 20 psi. Pressures within distribution mains are not limited to a set maximum. All new services with static pressure above 80 psi require a pressure-reducing valve (PRV) per plumbing code requirements.

5. Distribution Watermains and Appurtenances

SPU design standards for watermain and related distribution system appurtenances are described in the attached memorandum. These standards include minimum pipe sizes, valve and hydrant spacing requirements, and other applicable standards.

6. Telemetry Systems

SPU has replaced its analog tone telemetry SCADA system with a PC-based frame relay system and is in the process of expanding the number of monitoring locations. After the first phase of SCADA expansion is completed, the standard information collected by type of facility will include the following:

- Source treatment plants: Clearwell level, inflow, outflow, chlorine residual, pH, turbidity, fluoride
- Reservoirs: Level, inflow, outflow, control valve position
- Reservoir hypochlorite treatment plants: Chlorine residual concentration, hypochlorite feed rates
- Tanks and standpipes: Level
- Pump stations: Flow, suction pressure, discharge pressure, pump status
- Control valves: Flow, upstream pressure, downstream pressure, valve position
- Transmission pipelines: Pressure
- Pressure zones (more than 500 service connections): Pressure

7. Standby Power

SPU's water system largely serves its customers by gravity flow. Therefore, the need for standby power is limited to the source treatment plants, open reservoir booster treatment plants, the control center, and some pump stations that raise water to the higher elevations in the system that cannot be served by gravity flow. These situations are diverse enough that a single set of standards does not apply. SPU's approach is best illustrated by specific examples.

New chlorination facilities at the outlets of open reservoirs are equipped with emergency generators to support full treatment capacity during power outages. The Tolt Treatment Facility has emergency generator capacity to operate critical components of the facility, allowing it to meet the quantity and quality performance standards of the design-build-operate (DBO) service agreement. The Cedar Treatment Facility has emergency generator capacity to produce average day demands in accordance with the performance criteria of the DBO service agreement. The Cedar Treatment Facility also provides standby power for the Lake Youngs Pump Station, which serves Cedar River and Soos Creek Water Districts.

Higher elevations in the distribution system can typically receive water from one of several pump stations, some of which are equipped with hydraulically-powered pumps unaffected by power outages. Combined with the reliability of the electric grid within city limits, the probability of losing all pumps serving a particular pressure zone is relatively low. Where this assumption cannot be made, an emergency generator connection or a diesel-driven pump is provided.

A service reliability analysis was done in preparation for the Y2K turnover. A new diesel drive pump was added at Bitter Lake Reservoir. Otherwise, the analysis found SPU has portable emergency generator capability to supply vulnerable areas in response to a multi-day regional power failure.

Seattle Public Utilities

MEMORANDUM

DATE: February 10, 2006

TO: File

FROM: Charles Oppelt, Capital Projects Coordinator, SPU Engineering Division

SUBJECT: Design Standards and Definition of Standard Water Main

Attached is a new version of the Design Standards for Distribution Water Mains memorandum. This document updates the May 12, 1987 Water Department memo from Walter Anton that SPU provided as an appendix to the 2001 Water System Plan (WSP). The following document includes all of the information in the 1987 memo with the following updates. The updates include changes to the Standard Plan numbers, revisions to the text for Department reorganization from Seattle Water Department to Seattle Public Utilities and Superintendent to Director of said Departments, updating of AWWA Standards to the current versions used by SPU *(see Attachment 1 below)* and changes to the desirable watermain pressure standards resulting from the February 1, 2005 SPU Policy on Distribution System Water Service Pressure – Number: SPU-RM-006.

The Definition of Standard Water Mains *(see Attachment 2)* below, required no updates from the 1987 version.

CAO
Attachments
cc: Michael Brennan
Charlie Madden
Eugene Mantchev

Seattle Public Utilities Distribution Watermain Requirements & Design Standards *

Distribution Watermain Standards – 2” through 12” sizes

Pipe Standards – 2” size

Type K copper soft coil, with brass flared or compression fittings

Pipe Standards – 4” through 12” sizes

Ductile Iron Pipe Class 52 **
Restrained joint
Slip joint
Mechanical joint
Cement lined

Depth Standards

2”, 4”, 6” and 8” sizes – 35” of cover below established street grade as determined by the agency having control over the street involved.
10” size – 40” of cover below established street grade.

12” size – 43” of cover below established street grade.

16” to 30” – 36” of cover below established street grade.

Location Standards

Watermain in public, deeded street – Watermain may, at the option of Seattle Public Utilities, be installed in a private street or in an easement.

Platted Streets – 30’ or wider (Standard Plan # 030).

10’ East of centerline	North-South streets
10’ North of centerline	East-West streets

Streets or Easements – 20’ to 30’

5’ West of margin	North-South streets
5’ South of margin	East-West streets

Easements less than 20’
Location to be determined on a case by case basis, if allowed.

* All standards and requirements subject to change, modification, or use as determined by the Director of SPU in accordance with Seattle Municipal Code 3.22.30 and other Seattle Municipal Code authority.

** PVC pipe, AWWA C-900 may be used in highly corrosive soils if approved by the Director of SPU.

Minimum Size Standards

2” – Dead end streets/easements less than 400’ in length, single family/duplex zoning, no fire hydrants required, maximum of 6 lots to be served, maximum metered service size allowed (1”) – all service tees to be installed with the main.

4” – Dead end streets/easements less than 400’ in length and no fire hydrants required. More than 6 lots to be served or zoning other than single-family/duplex.

6” – Dead end streets/easements in single family/duplex zoning or single hydrant required (1000 GPM fire flow available).

8” – Through streets and easements – residential areas.

12”- Through streets and easements – industrial, commercial and mixed use areas.

Corrosion Protection Standards

To be applied in areas where soil resistivity is less than 3000 ohm-cm, or shale rock areas, garbage fill areas, organic soil areas, or other soil where corrosive conditions exist. One or more of the following may be required:

1. Poly-wrap, Tape Coating or other protective coating
2. Select backfill – bedding
3. Joint bonding
4. Cathodic protection

Hydrant Spacing Standards

Approx. 400’ on centers – residential areas

Approx. 300’ on centers – industrial, commercial areas

Valve Spacing Standards

Valves located at margins of street intersections where mains intersect, and otherwise such that a break or other failure will not affect more than 1/4 mile of arterial mains, 500 feet of mains in commercial districts, or 8OO feet of mains in residential districts.

Separation Standards – Sewer/Water

In accordance with the sewer/water separation standard drawings #286 a&b.

Desirable Watermain Pressure Standards

Minimum – 30 psi for new installations.
Maximum – none

If an SPU-initiated system reconfiguration causes a permanent pressure increase of 10 psi or greater at a water service, customers expected to see resultant pressures at their meters above 80 psi shall be given written notice of the pressure increase. In addition, an offer shall be extended by SPU to cover the cost of a PRV to be installed on the private property (with any limitations on cost and what method of installation would be used – SPU contractor, property owner installation and reimbursement, etc.), when a PRV is not already pre-existing on the property water system.

Watermain Appurtenance		Standard Plan
Pipe	Connections to Existing Watermain	300a
	Connections to Existing Watermain	300b
	Connections to Existing Watermain	300c
Hydrants	Hydrant Setting Detail	310a
	Hydrant Setting Detail	310b
	Hydrant Setting Detail	311a
	Hydrant Setting Detail	311b
	Fire Hydrant Marker Layout	312
	Wall & Requirements for Hydrants	313
	Fire Hydrant Locations & Clearances	314
Valve	Cast Iron Valve Box & Operating Nut Extensions	315a
	Cast Iron Valve Box & Operating Nut Extensions	315b
Concrete Blocking	Watermain Thrust Blocking Vertical Fittings	330a
	Watermain Thrust Blocking Vertical Fittings	330b
	Watermain Thrust Blocking Horizontal Fittings	331a
	Watermain Thrust Blocking Horizontal Fittings	331b
Blow Off	2” Blow-Off Detail Non-traffic	340a
	2” Blow-Off Detail Traffic	340b
Pipe Bedding	Watermain Pipe Bedding (Special)	350
Misc. Plans	Watermain Electrolysis Test Station	360
	Type 361 Valve Chamber Ring & Cover	361
	Joint Bonding for D.I.P. Watermains	362
	Isolating Coupling	363
	Pressure Reducing Valve Assemblies	
	Pressure Relief Valve Assemblies	
	Sample Station	
	Drinking Fountain	

Water Service Installation Standards - ¾”- through 12” sizes

Domestic Services

Standard Plan No.	735-1	3/4”	Domestic
	735-1	1”	Domestic
	735-2	1 1/2”	Domestic
	735-2	2”	Domestic
	735-8	4”	Domestic Compound
	735-9	6”	Domestic Compound
	735-8	3”	Domestic Compound

Combination Fire/Domestic Services

Standard Plan No.	735-4	4”
	735-5	6”
	735-6	8”
	735-11	10”

Fire Services

Standard Plan No.	735-3	2” fire
	735-10	4” fire
	735-10	6” fire
	735-10	8” fire
	735-10	10” fire
	735-10	12” fire

Watermain Extension Applications and Agreements (Developer extensions)

Watermain Extension Application and Agreement

Miscellaneous Standards

Watermain construction and financing options – LID – Special tap charge or private contract.

The contributing properties shall be zip tone shaded (Format #7*045* or equal) and labeled “contributing properties”.

At all fittings where the watermain changes direction, and at dead-ends, concrete thrust blocking or shackles shall be shown in accordance with the appropriate standard plan(s).

A profile shall be included on all plans.

Blowoffs or hydrants on all dead-ends. Drainage course for disposal of blowoff water.

Appropriate cross or tee for future extension.

Dead-end mains shall normally extend across the full width of property served.

Plans and profiles shall show existing or proposed underground utilities within the margins of the street.

Appurtenant pipe runs to hydrants, meters, blowoffs, etc., shall have alignment perpendicular to the watermain.

Other Reference Standards/Requirements

City of Seattle Fire Code
City of Seattle Plumbing Code
City of Seattle Zoning and Land Use Code
City of Seattle Water Code
City of Seattle Water Department Water Service Policy and other Administrative Rules
King County Fire Code.
King County Zoning and Land Use Codes
King County Road Standards
King County Plumbing Code
King County Franchises
Washington State RCWls, especially Chapter 35
Washington State Department of Transportation Franchises
Washington State Department of Transportation 1984 Standard Specifications for Roads, Bridges, and Municipal Utilities
Washington State Department of Transportation Utilities Accommodation Policy

City of Seattle Supplement to Washington State Department of Transportation 1984 Standard Specifications for Roads, Bridges and Municipal Construction

WAC-248-54-550 through 850
Design Standards for Public Water Supplies – D.S.H.S.

Minimum Design Standards for Community Water Supply Systems – H.U.D.

Recommended Standards for Water Works – Great Lakes – Upper Mississippi River Board of State Sanitary Engineers (Ten State Standards)

AWWA Standards – American Water Works Association (primarily material standards) – See attached Standards list

Grading Schedule for Municipal Fire Protection and Guide for Determination of Required Fire Flow – Insurance Services Office

Various AWWA Manuals (e.g., M-ll, Steel Pipe Design and Installation)

Charles Oppelt
Design Standards and Guidelines Coordinator

TO FILE,
Design standards and guidelines program

ATTACHMENT 1

Current AWWA Standards - December 2005

This list includes American Water Works Standards in effect on Dec 31, 2005
WITHDRAWN standards listed are noted as such and have been retained by the SPU for Engineering Branch reference on existing systems.

Groundwater and Wells

A100-97: Water Wells

Filtration

B100-01: Filtering Material
B101-01: Precoat Filter Media
B102-04: Manganese Greensand for Filters

Softening

B200-03: Sodium Chloride
B201-03 Soda Ash
B202-02: Quicklime and Hydrated Lime

Disinfection Chemicals

B300-04: Hypochlorites
B301-04: Liquid Chlorine
B302-05: Ammonium Sulfate
B303-05: Sodium Chlorite
B304-05: (ANSI) Liquid Oxygen for Ozone Generation

Coagulation

B402-00: Ferrous Sulfate
B403-03: Aluminum Sulfate: Liquid, Ground, or Lump
B404-03: Liquid Sodium Silicate
B405-00: Sodium Aluminate
B406-97: Ferric Sulfate
B407-05: Liquid Ferric Chloride
B408-03: Liquid Polyaluminum Chloride
B451-04: Poly (Diallyldimethylammonium Chloride)
B452-98: EPI-DMA Polyamines
B453-01: Polyacrylamide

Scale and Corrosion Control

B501-03: Sodium Hydroxide (Caustic Soda)
B502-05: Sodium Polyphosphate, Glassy (Sodium Hexametaphosphate)
B503-05: Sodium Tripolyphosphate
B504-05: Monosodium Phosphate, Anhydrous
B505-05: Disodium Phosphate, Anhydrous
B510-00: Carbon Dioxide
B511-05: Potassium Hydroxide
B512-02: Sulfur Dioxide
B550-05: Calcium Chloride

Taste and Odor Control

B600-05: Powdered Activated Carbon

B601-05: Sodium Metabisulfite

B602-02: Copper Sulfate

B603-03: Potassium Permanganate

B604-96: Granular Activated Carbon

B605-99: Reactivation of Granulated Activated Carbon

Prophylaxis

B701-99: Sodium Fluoride

B702-99: Sodium Fluorosilicate

B703-00: Fluorosilicic Acid

Ductile-Iron Pipe and Fittings

C104/A21.4-03 Cement-Mortar Lining for Ductile-Iron Pipe and Fittings for Water

C105/A21.5-05: Polyethylene Encasement for Ductile-Iron Pipe Systems

C110/A21.10-03: Ductile-Iron and Gray-Iron Fittings for Water

C111/A21.11-00: Rubber-Gasket Joints for Ductile-Iron Pressure Pipe and Fittings

C115/A21.15-99: Flanged Ductile-Iron Pipe with Ductile-Iron or Gray-Iron Threaded Flanges

C116/A21.16-03: Protective Fusion-Bonded Epoxy Coatings Int. & Ext. Surf. Ductile-Iron/Gray-Iron Fittings

C150/A21.50-02: Thickness Design of Ductile-Iron Pipe

C151/A21.51-02: Ductile-Iron Pipe, Centrifugally Cast, for Water or Other Liquids

C153/A21.53-00: Ductile-Iron Compact Fittings for Water Service

Steel Pipe

C200-97: Steel Water Pipe 6 In. (150 mm) and Larger

C203-02: Coal-Tar Protective Coatings & Linings for Steel Water Pipelines, Enamel & Tape, Hot-Applied

C205-00: Cement-Mortar Protective Lining and Coating for Steel Water Pipe, 4 In. (100 mm) and Larger, Shop Appli

C206-03: Field Welding of Steel Water Pipe

C207-01: Steel Pipe Flanges for Waterworks Service, Sizes 4 In. Through 144 In. (100 mm Through 3,600 mm)

C208-01: Dimensions for Fabricated Steel Water Pipe Fittings

C209-00: Cold-Applied Tape Coatings for the Exterior of Special Sections, Connections, and Fittings for Steel Water Pipe

C210-03: Liquid-Epoxy Coating Systems for the Interior and Exterior of Steel Water Pipelines

C213-01: Fusion-Bonded Epoxy Coating for the Interior and Exterior of Steel Water Pipelines

C214-00: Tape Coating Systems for the Exterior of Steel Water Pipelines

C215-04: Extruded Polyolefin Coatings for the Exterior of Steel Water Pipelines

C216-00: Heat-Shrinkable Cross-Linked Polyolefin Coatings for the Exterior of Special Sections, Connections, and Fitting

C217-04: Petrolatum and Petroleum Wax Tape Coatings for Exterior of Connections and Fittings for Steel Water Pipelines

C218-02: Coating the Exterior of Aboveground Steel Water Pipelines and Fittings

C219-01: Bolted, Sleeve-Type Couplings for Plain-End Pipe

C220-98: Stainless-Steel Pipe, 4 In. (100 mm) and Larger

C221-01: Fabricated Steel Mechanical Slip-Type Expansion Joints

C222-99: Polyurethane Coatings for the Interior and Exterior of Steel Water Pipe and Fittings

C223-02: Fabricated Steel and Stainless Steel Tapping Sleeves

C224-01: Two-layer Nylon-11 Based Polyamide Coating System for Interior and Exterior of Steel Water Pipe and Fittings

C225-03: Fused Polyolefin Coating Systems for the Exterior of Steel Water Pipelines

Concrete Pipe

C300-04: Reinforced Concrete Pressure Pipe, Steel-Cylinder Type

C301-99: Prestressed Concrete Pressure Pipe, Steel-Cylinder Type

C302-04: Reinforced Concrete Pressure Pipe, Noncylinder Type

C303-02: Concrete Pressure Pipe, Bar-Wrapped, Steel-Cylinder Type

C304-99: Design of Prestressed Concrete Cylinder Pipe

Asbestos-Cement Pipe

C400-03: Asbestos–Cement Pressure Pipe, 4 In.–16 In. (100 mm–400 mm), for Water Dist. & Trans.

C401-03: Selection of Asbestos–Cement Pressure Pipe, 4 In.-16 In. (100 mm-400 mm), for Water Dist. Sys.
C402-05: Asbestos-Cement Transmission Pipe, 18 In Through 42 In. (450 mm Through 1,050 mm) for Water Supply Service
C403-05: The Selection of Asbestos–Cement Transmission Pipe, Sizes 18 In. Through 42 In. (450 mm Through 1,050 mm),

Valves and Hydrants

C500-02: Metal-Seated Gate Valves for Water Supply Service

C501-92: WITHDRAWN -Sluice Gates

C502-05: Dry-Barrel Fire Hydrants

C503-05: Wet-Barrel Fire Hydrants

C504-00: Rubber-Seated Butterfly Valves

C506-78(R83): WITHDRAWN - Backflow Prevention devices

C507-05: Ball Valves, 6 In. Through 48 In. (150 mm Through 1,200 mm)

C508-01: Swing-Check Valves for Waterworks Service, 2 In. (50 mm) Through 24 In.(600 mm) NPS

C509-01: Resilient-Seated Gate Valves for Water Supply Service

C510-97: Double Check Valve Backflow Prevention Assembly

C511-97: Reduced-Pressure Principle Backflow Prevention Assembly

C512-04: Air Release, Air/Vacuum, and Combination Air Valves for Waterworks Service

C513-05: Open-Channel, Fabricated-Metal, Slide Gates and Open-Channel, Fabricated-Metal Weir Gates

C515-01: Reduced-Wall, Resilient-Seated Gate Valves for Water Supply Service

C540-02: Power-Actuating Devices for Valves and Slide Gates

C550-05: Protective Epoxy Interior Coatings for Valves and Hydrants

C560-00: Cast-Iron Slide Gates

C561-04: Fabricated Stainless Steel Slide Gates

C563-04: Fabricated Composite Slide Gates

Pipe Installation

C600-05: Installation of Ductile-Iron Water Mains and Their Appurtenances

C601-81: WITHDRAWN - Disinfecting Water Mains

C602-00: Cement-Mortar Lining of Water Pipelines in Place—4 In. (100 mm) and Larger

C603-05: Installation of Asbestos Cement Pressure Pipe

C605-05: Underground Installation of Polyvinyl Chloride (PVC) Pressure Pipe and Fittings for Water

C606-04: Grooved and Shouldered Joints

Disinfection of Facilities

C651-05: Disinfecting Water Mains

C652-02: Disinfection of Water-Storage Facilities

C653-03: Disinfection of Water Treatment Plants

C654-03: Disinfection of Wells

Meters

C700-02: Cold-Water Meters—Displacement Type, Bronze Main Case

C701-02: Cold-Water Meters—Turbine Type, for Customer Service

C702-01 : Cold-Water Meters—Compound Type

C703-96 (R04): Cold-Water Meters—Fire Service Type

C704-02 : Propeller-Type Meters for Waterworks Applications

C706-96 (R05): Direct-Reading, Remote-Registration Systems for Cold-Water Meters

C707-05: Encoder-Type Remote-Registration Systems for Cold-Water Meters

C708-05: Cold-Water Meters Multijet Type

C710-02: Cold-Water Meters—Displacement Type, Plastic Main Case

C712-02: Cold-Water Meter--Singlejet Type

C713-05: Cold-Water Meters: Fluidic-Oscillator Type

C750-03: Transit-Time Flowmeters in Full Closed Conduits

Service Lines

C800-05: Underground Service Line Valves and Fittings (Also Included: Collected Standards for Service Line Materials)

Plastic Pipe

C900-97: Polyvinyl Chloride (PVC) Pressure Pipe, and Fabricated Fittings, 4 In.-12 In. (100 mm-300 mm), for Water Dist.

C901-02: Polyethylene (PE) Pressure Pipe and Tubing, ½ In. (13 mm) Through 3 In. (76 mm), for Water Service

C903-05: Polyethylene-Aluminum-Polyethylene Composite Pressure Pipes

C905-97: Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 14 In.-48 In. (350 mm-1,200 mm)

C906-99: Polyethylene (PE) Pressure Pipe and Fittings, 4 In. (100 mm) Th. 63 In. (1,575 mm), for Water Dist. and Trans.

C907-04: Injection-Molded Polyvinyl Chloride (PVC) Pressure Fittings, 4 In. Through 12 In. (100 mm Through 300 mm)

C908-01: PVC Self-Tapping Saddle Tees for Use on PVC Pipe

C909-02: Molecularly Oriented Polyvinyl Chloride (PVCO) Pressure Pipe, 4 In.-24 In. (100 mm-600 mm), for Water Distribut

C950-01: Fiberglass Pressure Pipe

Storage

Custom Manual/Standard Set: Flexible-Membrane Storage

Custom Manual/Standard Set: Steel Tanks

D100-96: Welded Steel Tanks for Water Storage

D101-53(R86): WITHDRAWN - Inspecting and repairing steel water tanks, standpipes, reservoirs, and elevated tanks, for water storage

D102-03: Coating Steel Water-Storage Tanks

D103-97: Factory-Coated Bolted Steel Tanks for Water Storage

D104-04: Automatically Controlled, Impressed-Current Cathodic Protection for the Interior of Steel Water Tanks

D110-04: Wire- and Strand-Wound, Circular, Prestressed Concrete Water Tanks

D115-95: Circular Prestressed Concrete Water Tanks With Circumferential Tendons

D120-02: Thermosetting Fiberglass-Reinforced Plastic Tanks

D130-02 : Flexible-Membrane Materials for Potable Water Applications

Pumping

E101-88 WITHDRAWN - ANSI Std for Vertical turbine pumps - Line shaft and submersible types

Plant Equipment

F101-02: Contact-Molded, Fiberglass-Reinforced Plastic Wash Water Troughs and Launders

F102-02: Matched-Die-Molded, Fiberglass-Reinforced Plastic Weir Plates, Scum Baffles, and Mounting Brackets

Utility Management

G100-05: Water Treatment Plant Operation and Management

G200-04: Distribution Systems Operation and Management

ATTACHMENT 2

Definition - Standard Watermains

Under the following conditions watermains would be considered standard:

A. Existing Watermains

1. Single family/duplex residential zoning *

   Dead end streets/easements less than 400 feet in length - no Fire hydrants required.

   4 inch or larger cast iron or
   Ductile iron pipe, and 2" copper pipe

   Dead end streets/easements with single standard fire hydrant and 1000 GPM fire flow available.

   6 inch or larger cast iron or
   Ductile iron pipe. (8 inch size or larger cast iron or
   Ductile iron pipe if more than one standard fire hydrant.)

   Through streets and easements with standard fire hydrant(s) and 1000 GPM fire flow available.

   6 inch or larger cast iron or Ductile iron pipe

2. All other zoning *

   8 inch or larger cast iron or ductile iron pipe.

* NOTE: All zoning - existing 16" and larger watermains shall all be considered as standard. For 12" and smaller size watermains, all existing watermains constructed before 1984 and constructed of materials other than cast iron, ductile iron pipe, or copper pipe shall be considered substandard.

B. New Watermains

New watermains shall conform to the latest Seattle Public Utilities Distribution Watermain Requirements and Design Standards.

Definition - Standard Fire Hydrant

Standard fire hydrant is a 6" or larger nominal size fire hydrant connected by a 6" or larger pipe to a 6" or larger watermain. New fire hydrants must conform to current Seattle Public Utilities requirements.

SEATTLE PUBLIC UTILITIES
2007 WATER SYSTEM PLAN

IV. DISTRIBUTION

APPENDIX C
DISTRIBUTION FACILITIES DESIGN AND CONSTRUCTION STANDARDS

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This appendix to the *2007 Water System Plan Update* (WSP) describes the standards and procedures followed by Seattle Public Utilities (SPU) in the installation of new water mains and the interior coating of water storage facilities. These requirements are intended to meet or exceed the design and construction standards referenced in WAC 246-290. Together with the City of Seattle's Standard Specifications (Seattle, 2000a) and Standard Plans (Seattle, 2000b), this material is intended to meet the requirements of the Department of Health (DOH) submittal exception process for distribution main construction and tank painting. By qualifying for this process and following the approved procedures and standards, SPU is provided a waiver from the requirement of DOH approval of individual projects.

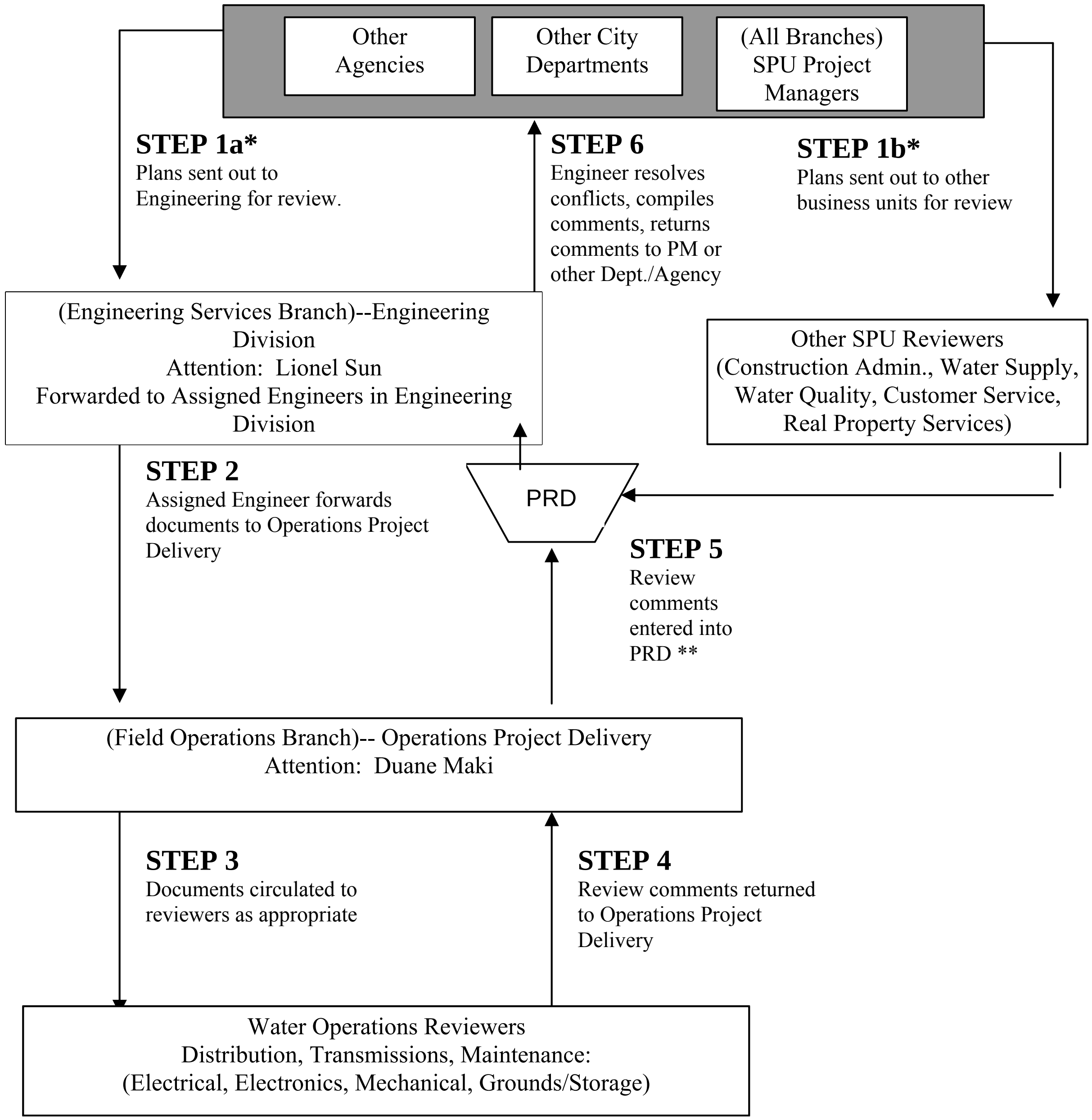
1. Project Review Procedures

All improvements and modifications to the water distribution system follow the Project Document Review Procedure. The distribution system Project Document Review Procedure process is presented as Exhibit 1. The Project Document Review Procedure is triggered at a point in the design phase when preliminary project documents are received from an external source such as a developer or other agency or at the point when internal SPU circulation of preliminary project documents occurs. These project documents are prepared in accordance with SPU Standards, Policies, and conditions set forth in the Water Availability Certificate (see Section 2 of this appendix). This phase of the project is represented in the schematic by the shaded box at the top.

Step 1a and 1b of the Project Document Review Procedure occur concurrently and are designed to initiate project review from Engineering services and other SPU organizational units. Project documents prepared within one unit of the Engineering Division are routed to one of the other units for review (Step 1a) and are also routed to other appropriate non-engineering SPU reviewers (Step 1b). Similar routing for review occurs for projects which include modifications of some sort to the water distribution system. Steps 2, 3, and 4 show the SPU internal document review routing process through the Field Operations Branch. All reviews are compiled at Step 5 when comments are entered into the Plan Review Database. In Step 6, the Engineering Division and Customer Service are responsible for resolution of conflicts, comment compilation including City Standards, and transmittal of materials to the SPU Project Manager and other City Departments, outside agencies, and developers. Once plans are approved, a permission letter, SPU Right-of-Way Permit, or City Street Use Permit is sent as appropriate for the project's location.

The Engineering division provides engineering reviews and acts as the centralized coordinator for all project documents related to the water utility infrastructure. All review comments are recorded in the Plan Review Database (PRD) managed by the Engineering Division.

Exhibit 1
Distribution System Project Document Review Procedures



***Steps 1a and 1b occur concurrently**
**** PRD is the Plan Review Database, used for review comment routing and is currently being upgraded.**

2. Policies and Requirements for Outside Parties

SPU has in place established developer requirements for design and installation of extension or replacement of Seattle's water distribution system. These documents and requirements are accessible through the City of Seattle website at www.seattle.gov/util/engineering/obtain_utility_services/index.asp. The documents available for outside parties include:

Developers and Property Owners

- Application to Change SPU's Distribution System
- Hydrant Testing
- Property Owner Contract
- Standard Charges
- Surety Instrument
- Transfer of Ownership
- Easement Information

Engineers

- General Notes on Plans: 4" – 12" Mains
- Selective Notes on Plans: 4" – 12" Mains
- Information Sheets for Engineers
- Hydrant Test Request Procedure

Contractors

- General Information
- Insurance Requirements
- Hydrant Information
- Water Quality Checklist
- Survey Requirements

Outside parties alter the water distribution system and the ability to deliver water if development requires replacement or extension of existing water mains, pressure zones, etc. These changes to water supply due to development are stated on the Water Availability Certificate that is issued at the time of a building permit or land use change application. Developers must follow established requirements and procedures in both the design and installation of new water infrastructure. SPU reviews and approves the design submitted by the developer and inspects the installation by the developer's contractor. Infrastructure design is based on SPU's engineering design requirements, Policies and City Standard Specifications (Seattle, 2005), as well as other engineering considerations.

Before a developer can begin construction, the developer is required to contract with SPU to change the water distribution system. The developer-SPU contract addresses the standard charges for plan review, easement processing if needed, construction inspection, water quality testing, connection to the existing SPU system, and any other work which SPU performs related to the developer's project. Additionally, the developer must also provide SPU with a surety instrument. All developer plans must be submitted by the developer's engineer for SPU review and approval. Finally, the developer's contractor must conduct a preconstruction meeting with SPU staff to identify and agree upon construction start dates.

3. Design Standards

Performance Standards and Sizing Criteria are addressed in a separate appendix on System Design Standards.

4. Construction Standards

The 2005 City of Seattle Standard Specifications (Seattle, 2005) includes:

- Pipe and Fittings
- Trench Excavation
- Bedding and Backfill
- Pipe Installation
- Valves
- Hydrants
- Service Connections
- Irrigation System (Backflow Prevention)
- Water (for concrete, irrigation and hydrant use)
- Distribution Materials

These specifications include construction materials and methods of construction. Performance standards desired and expected are reflected in the construction standards. All public and private construction within the City of Seattle public right-of-way must comply with the Standard Specifications. The 2005 City of Seattle Standard Plans (Seattle, 2005) supplement the Standard Specifications.

Where applicable, specific standard references to professional and technical society standards (such as AWWA, APWA) have been incorporated. As standards are upgraded, there is a system in place to incorporate these updates and revisions. For the painting of the interior of water tanks, coatings are limited to those that have been certified to meet NSF standard 61.

5. Construction Certification and Follow-up Procedures

5.1 Preconstruction

SPU's construction standards, the 2005 City of Seattle Standard Specifications (Seattle, 2005) and the 2005 Seattle Standard Plans (Seattle, 2005), serve as the basis for all public works project contract documents. These standards are made available to all prospective bidders along with the bid documents for each project at SPU's Engineering Records Vault bid counter. The standards are revised and supplemented in individual water distribution main project plans and specifications.

Prior to the start of a water distribution main construction project, a preconstruction meeting is held with representatives of SPU design, project management, construction, water quality, and operations staff; the contractor and subcontractors; and other involved parties, such as a developer or consulting engineer. At the preconstruction meeting, SPU's procedures for submittals, inspection, water quality control, connection(s) to the existing water system, and installation of meters are discussed.

Submittals are required from the contractor for review by SPU before water distribution main installation is allowed to begin. When contractors perform their own survey, grade sheets are submitted to verify pipeline grade during construction. The contractor's proposed sources of construction materials are submitted and reviewed by SPU's Materials Testing Laboratory. Specific construction materials submittals, including shop drawings, catalog cuts, and technical data are also reviewed, as required.

5.2 Construction Inspection

SPU Construction Engineering personnel perform continuous on-site inspection during installation of water distribution mains to verify conformance with appropriate AWWA, DOH, and City of Seattle Standard Specifications. The procedures listed below are followed during inspection:

Grade and Alignment. Grade and alignment of the new water distribution main are verified by SPU Construction Engineering personnel. Deviations from the plan grade and alignment are noted.

Existing Utilities. Encounters with existing utilities, both marked and unmarked, are noted by SPU Construction Engineering personnel. Proper separation between the new water distribution main and existing utilities is ensured. In the case of encountered sanitary sewers and storm drains where sufficient separation is not available, replacement of the section of sewer/drain pipe crossing over or under the pipe with new ductile iron pipe is required.

Trench Excavation. Trench excavation is observed to verify sufficient depth of cover over water distribution mains (35 inches of cover for 8-inch diameter and smaller mains, 40 inches of cover for 10-inch diameter mains, and 43 inches of cover for 12-inch diameter mains as per Seattle Standard Specifications 7-10.3(5)C and Seattle Standard Plan No. 030). Extra excavation is required if unsuitable material is found at the bottom of the trench.

Pipe Bedding and Backfill. Proper pipe bedding is ensured by SPU Construction Engineering Personnel, in accordance with Seattle Standard Specifications 7-10.3(9). Trench backfill is also observed to conform to Seattle Standard Specifications 7-10.3(10). Unsuitable backfill material is rejected. Proper compaction of the bedding and backfill is ensured and tested by SPU Materials Laboratory personnel, or a private, certified testing firm in accordance with Seattle Standard Specifications 7-10.3(11).

Pipe Installation. Prior to installation of new water distribution mains, SPU Construction Engineering personnel inspect pipe and appurtenances for proper size, material, thickness class, and type of joint. Proper storage and handling of the pipe before it is placed in the trench is ensured. All standing water in the trench is directed to be removed by the contractor before the pipe is laid. Proper cutting of pipe is also observed.

All pipe bell and spigot ends are inspected for cleanliness before jointing. Proper assembly and tightening of mechanical or restrained joint systems is observed. Deflection of joints is observed to not exceed allowable limits of the type of joint.

Thrust Restraint. Thrust restraint measures are observed to conform with the design requirements. Thrust blocking is ensured to cover a sufficient amount of area based on pipe diameter and soil type (Seattle Standard Plans No. 330.1a&b, 331.1a&b) and be of an appropriate mix of concrete. Shackle rods, when used, are observed to be of the proper type, number, and diameter.

Corrosion Protection. When corrosion protection and/or electrolysis monitoring measures are specified, SPU Construction Engineering personnel observe that they are properly installed. Prior to exothermic pipe bonding, the bonding surface is observed to be clean and free of paint, primer, and other coating materials. The soundness of the welds is observed and tested with a glancing blow with a 16 ounce hammer. Joint continuity tests, when specified, are observed to meet minimum levels. Polyethylene wraps are observed to be continuous and free from tears.

Installation of Appurtenances. SPU Construction Engineering personnel verify proper installation of valves, hydrants, blowoffs, and other appurtenances. Proper installation of hydrant tee thrust restraint systems is observed and verified.

5.3 Pressure Testing

SPU Construction Engineering personnel perform hydrostatic pressure tests of all installed water distribution mains according to the requirements of Seattle Standard Specifications 7-11.3(11). Ductile iron water distribution mains 12 inches in diameter or smaller are tested to a pressure of 300 psi. Pipes 16 inches in diameter or larger are tested to 250 psi unless otherwise specified. The test pressure is maintained without pumping for 15 minutes for sections of water distribution main up to 1,500 feet long. A pressure drop of not more than 15 psi, with no visible leaks, during this time is considered acceptable. In-line gate valves will be acceptable if no immediate loss of pressure is registered on gauge when the valve is being checked. Hydrant valves are tested for five minutes. In-line valves are tested on each side and hydrant valves are tested on the water distribution main side only. A pressure drop of not more than 5 psi during this time, with no visible leaks, is considered acceptable. Water distribution mains not passing a pressure test are corrected and retested.

Pressure tests are recorded using a Bristol Babcock portable pressure recorder, using a 0-500 psi chart set at a 96-minute duration. Each test interval is indicated on the chart, along with whether the entire test was considered acceptable. Project information, date of test, and the name of the inspector performing the test are also recorded on the chart. Charts are maintained with project records.

5.4 Disinfection, Flushing, and Water Quality Sampling

SPU Construction Engineering personnel ensure that proper disinfection and flushing are performed and sample ports are provided during water distribution main installation. They coordinate sampling of the main with SPU Customer Service Water Quality Control staff.

Disinfection. SPU Construction Engineering personnel verify that chlorine for pipeline disinfection is applied through one of three allowed methods. In water distribution main installation, dry calcium hypochlorite (65-70 percent chlorine) is applied on a pipe-by-pipe basis in an amount sufficient to provide an initial dosage of at least 25 mg/l free chlorine. In circumstances where this is not feasible, gas chlorine or liquid sodium hypochlorite is applied as the disinfectant. The amount of chlorine required for each method for each diameter of pipe is specified in section 7-11.3(12) of the Seattle Standard Specifications.

Flushing. After a sufficient chlorine residual and contact time has been verified by SPU Water Quality Control personnel, the installed water distribution main is flushed. If dry calcium hypochlorite is the method of disinfection, a flushing velocity of at least 2.5 feet per second is required. Installed water distribution mains are flushed for at least five minutes for every 150 feet of new water distribution main and at least a 30-minute minimum.

Water Quality Sampling and Testing. Water quality samples are collected by SPU Water Quality Control personnel at intervals of 500 lineal feet or less along a new water distribution main. Samples are analyzed by the SPU Water Quality Laboratory for total coliform. Samples showing a presence of coliform bacteria are considered unsatisfactory and disinfection, flushing, and sampling of the distribution main is repeated (Seattle Standard Specifications 7-11.3(12)M). If samples exceed requirements for any reason other than coliform, the water distribution main is flushed and re-sampled.

Connection to Existing Distribution System. After satisfactory laboratory results are obtained, the installed water distribution main is connected to the existing distribution system. SPU water distribution crews make the physical connection with the aid of the contractor. SPU personnel ensure that, when possible, the total length of pipe required to connect the end of the installed water distribution main to the existing system is less than one standard pipe length of 18 feet. When this is not possible, SPU personnel require the contractor to predisinfect the connection pieces and arrange for water quality sampling of those pieces.

5.5 Procedures for Preparation and Retention of Design and Construction Drawings

Water distribution main design drawings are produced by both SPU Water Design staff and outside engineering staffs. Contract drawings are used to record bid item pay quantities, "as-built" notations and corrections, and all work added or deleted by change order. At the completion of construction, a set of "as-built" drawings is transmitted to SPU Technical Resources Section in the Engineering Support Division of the Engineering Services Branch for transfer to a reproducible medium. A copy is created on a storage medium and given to the SPU Engineering Records Vault, a repository of project information. All projects are assigned a unique vault plan number that is used to catalog the completed construction record drawings. Electronic design drawing files are stored by SPU Technical Resources Section. They are used to create contract drawings that are stamped and signed and then reproduced for advertisement and the use of the contractor and SPU Construction Engineering personnel. Corrected "as-built" record drawings are also transmitted to SPU Geographic Information Systems (GIS) personnel (Data Services, Information and Technology Division, Finance and Administration Branch), who transfer the project information to the City of Seattle GIS database. Within 60 days of completion of all water distribution main projects, a *Construction Report for Public Water System Projects* is submitted to DOH, in accordance with WAC 246-290-040.

SEATTLE PUBLIC UTILITIES
2007 WATER SYSTEM PLAN

IV. DISTRIBUTION

APPENDIX D

DISTRIBUTION SYSTEM RENEWAL STRATEGY

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BROWN AND CALDWELL

Technical Memorandum

Seattle Public Utilities
Water Plan Update (28901)
Task 7 – Distribution System Renewal Strategy

Date: March 2006

To: Eugene Mantchev, SPU
Bill Wells, SPU
Jon Shimada, SPU
Tim Skeel, SPU
Joan Kersnar, SPU

From: Darin Johnson, BC

Copy to: Andrew Lee, BC
Corinne DeLeon, BC
Scott Anschell, BC
File

RE: Distribution System Renewal Strategy Summary

Introduction

Seattle Public Utilities' (SPU's) distribution system renewal program provides a high level of service to its customers while minimizing the life cycle cost of the system. SPU's current levels of water main breaks, leakage, and outages are currently at very low level in comparison to other utilities nationwide and are not projected to increase to levels of concern over the next 20 years. The program's rehabilitation and replacement strategies are consistent with industry best management practices and SPU has procedures in place to gather more data in the future and adjust the program strategies if it becomes necessary.

The renewal program provides long term and short term pipeline rehabilitation and replacement planning while taking into account indirect social costs such as customer outages and traffic impacts. The tools used within the renewal program, the Water Main Replacement Model and Waverider, are repeatable and supportable methods to make decisions about capital expenditures and project reactive costs and system performance.

This document addresses the following topics:

- Distribution system background
- SPU's approach and tools for replacement planning
- Long-range projections of reactive cost for repair of leaks

- Current and projected system leakage
- Current and projected system outage rates

The following sections describe the relative ages and repair histories of the various pipelines that comprise SPU's water distribution system.

SPU's water system consists of over 1,800 miles of transmission and distribution pipes that deliver potable water to over 183,000 water services. These pipes are made up of various materials, including ductile iron, cast iron, steel, concrete, and galvanized steel and iron. The average age of pipes within the SPU system is 60 years. Figure 1 shows the length of SPU water pipes installed each year through 2003.

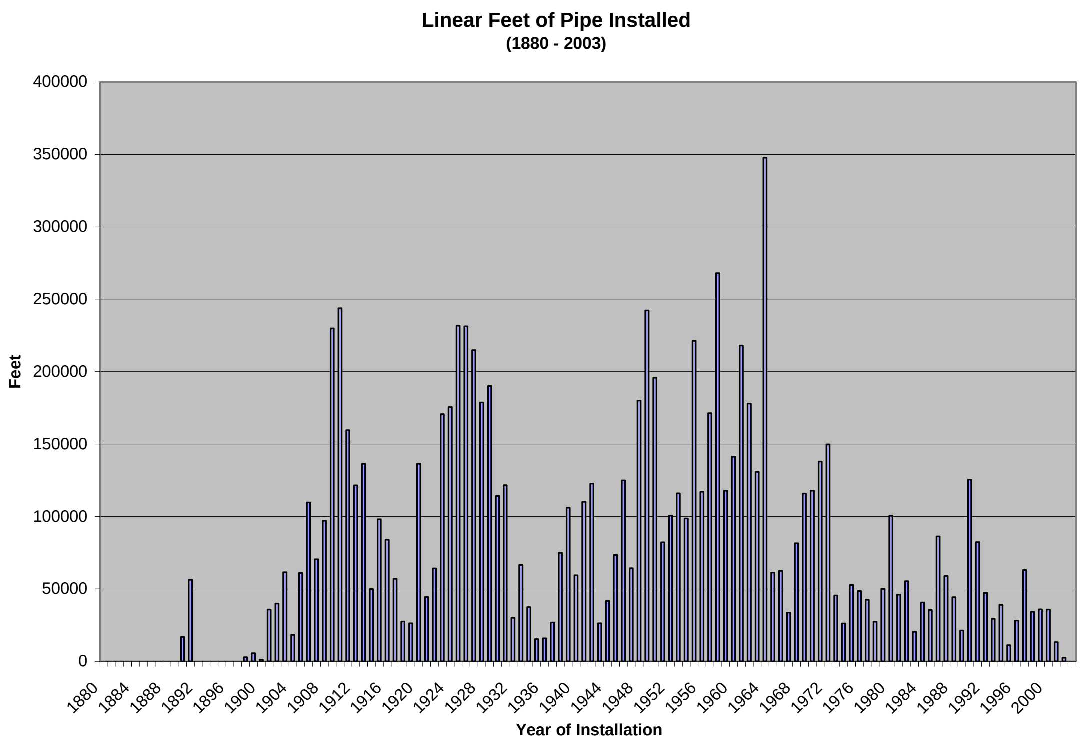


Figure 1 – Length of SPU Water Pipe Installed Each Year Through 2003

As part of the water system comprehensive plan, surveys were sent out on behalf of SPU asking other agencies about system history and policies including:

- System age
- Current and projected leakage
- Replacement and Renewal Strategies
- Levels of service

The utilities surveyed vary in size from Los Angeles Department of Water and Power (LADWP), with 708,000 retail service connections, to Clark Public Utilities District (PUD), with 63,000. SPU's water system is older than most of the other utilities', with the exception of Philadelphia Water Department and the San Francisco Public Utilities Commission (SFPUC).

See Appendix A – Agency Surveys for the survey responses.

Approach and Tools for Replacement Planning

Seattle Public Utilities utilizes a life-cycle cost approach to rehabilitation and replacement (R&R) planning. The life-cycle cost of an asset is the cost of owning, operating, maintaining, and disposing of that asset over its economic life. In addition to traditional design and construction costs, social and environmental costs are also included in the life-cycle cost analysis. Life-cycle cost is the total cost of ownership of an asset over its life, usually expressed as a present value or annualized cost. SPU's approach to pipeline rehabilitation and replacement is based on industry-accepted best practices for infrastructure asset management, which are widely used by water utilities in Australia, New Zealand, the United Kingdom, and more recently by utilities in the United States.

In general, pipeline replacement is economically justified when the cost of replacement is lower than the projected cost of future failures to that pipe. Specifically, when the marginal expected repair cost (probability of failure times repair cost) plus indirect social costs for a pipe in a given year is higher than the annualized cost (i.e., the cost spread over the expected life) of installing the new pipe, the pipe should be replaced. The sum of the repair cost and the replacement cost gives the life-cycle cost of ownership. As the life increases, the capital cost decreases (because replacement intervals are less frequent), but the repair cost increases (because the longer the pipe is in service, the more likely it is to fail. The economic life is the period that an asset can be economically owned and operated to minimize life-cycle cost.

SPU's approach to planning pipe replacement is based on two models, one for short-term and one for long-term planning. The long-term model is called Waverider; it uses the current age of the system and the estimated economic life of the various types of pipe in order to project spending for replacement and repairs of the entire distribution system into the future. The second model, for short-term planning, is called the Pipe Replacement Model. It considers pipes with reported leaks to determine whether they have reached end of economic life and should be replaced.

Waverider Model

The Waverider model breaks the pipe population into categories based on pipe material, size, and manufacture. The categories are intended to reflect the different aging characteristics and different repair and replacement costs of different types of pipe. For example, small diameter, cast iron pipe installed before 1920 is expected to have a longer economic life than cast iron pipe installed between 1920 and 1940; both of these groups are expected to last longer than cast iron pipe installed after 1940. The differences in economic life, and therefore categories of pipe, are based on current and historical SPU repair data. In this case, the differences in economic life are due to changes in materials and construction standards over time, which causes the rate of deterioration of the pipes to vary.

Replacement cost is projected by Waverider by assuming that pipes will be replaced when they reach their end of economic life. The model considers the current age distribution of each pipe category to determine the length of pipe and cost in each year into the future. These costs are then “smoothed” by distributing them on a normal curve centered at the economic life, in order to give a more realistic spending projection. As shown in Figure 3, the replacement cost projection from Waverider is a current annual cost of about $2 million, reaching a peak of $38 million in 2103.

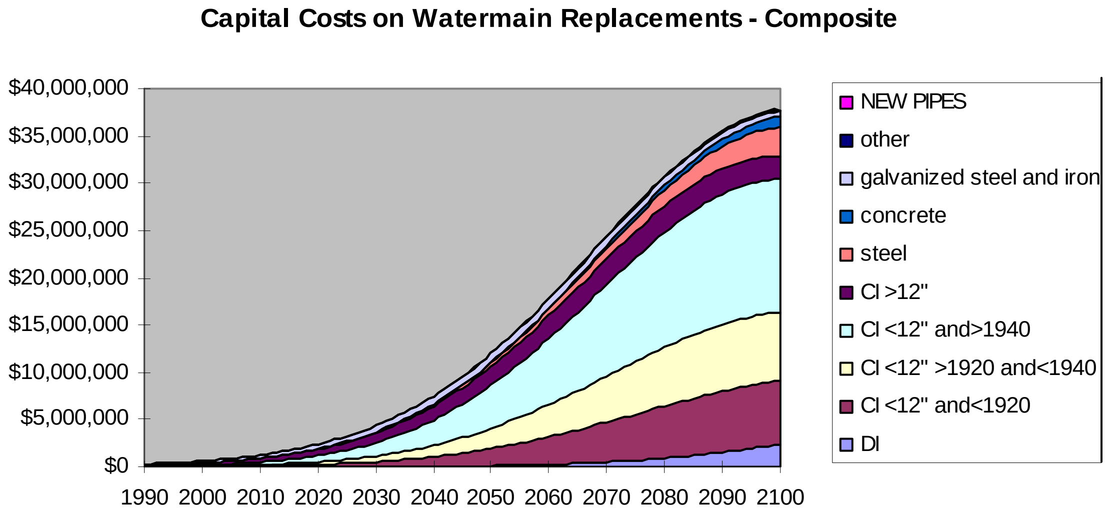


Figure 3. Long-Range Pipe Replacement Projection from Waverider

Waverider recognizes that the reactive costs for repair of leaking pipes will be high enough to justify replacement at the end of economic life for each pipe category. Reactive costs in the years leading up to end-of-life are estimated based on failure probability curves for each pipe category. The parameters defining these curves (and the economic life for each category) are adjusted by SPU so that the current number of leaks and replacement cost in the model match the actual numbers seen by SPU. As shown in Figure 4, the reactive repair cost projection from Waverider is a present annual cost of about $1 million, increasing to nearly $16 million in 2097.

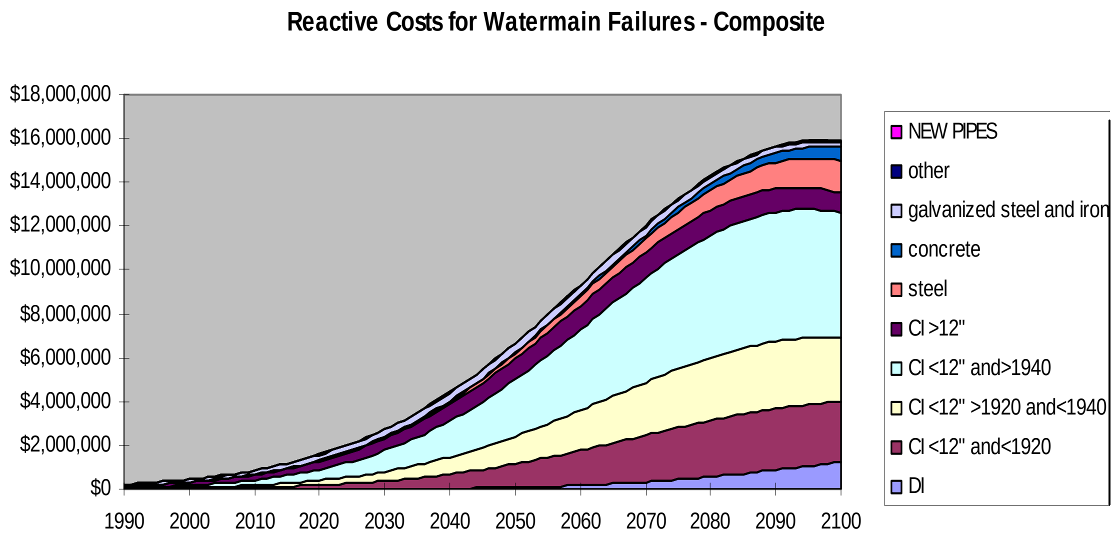


Figure 4. Long-Range Pipe Reactive Cost Projection from Waverider

Waverider is described in more detail in Appendix B – Waverider Document.

Pipe Replacement Model

The pipe replacement model provides an economic justification for replacing aging pipes based on the benefit of avoided risk. Pipes with a series of recent failures (i.e., leaks or breaks) are analyzed to determine whether they ought to be replaced in the near-term. These pipes are identified quarterly, based on the most recent leak data, which is compared with historical leak data in the GIS to identify pipe replacement candidates. The model compares the cost of a new pipe to the increasing cost of repairs for the existing pipe to determine whether replacement or continued repair is more cost-effective.

In order to determine whether a pipe should be replaced, the pipe replacement model performs the following:

- Calculates the annualized cost of a new pipe.
- Calculates the marginal cost (the expected repair cost times the probability of failure) for the existing pipe. The marginal cost includes indirect cost for service outages, water loss, and traffic impacts.
- Compares the annualized cost of a new pipe with the expected marginal cost of the existing pipe.

The annualized cost of a new pipe can be thought of as the “annual payment” SPU would have to make to finance this pipe over its entire economic life. It must include not only the initial, fixed cost for materials and installation but also the projected risk cost throughout the life of the pipe.

The Pipe Replacement Model then compares the annualized cost of a new pipe with the expected marginal cost of the existing pipe. If the annualized cost of the new pipe is lower than the marginal risk cost of the existing pipe, then it is less expensive to replace the pipe. On the other hand, if the risk cost is smaller, then it is cheaper to continue to operate the existing pipe and repair it when it leaks. Figure 2 displays this optimization process graphically.

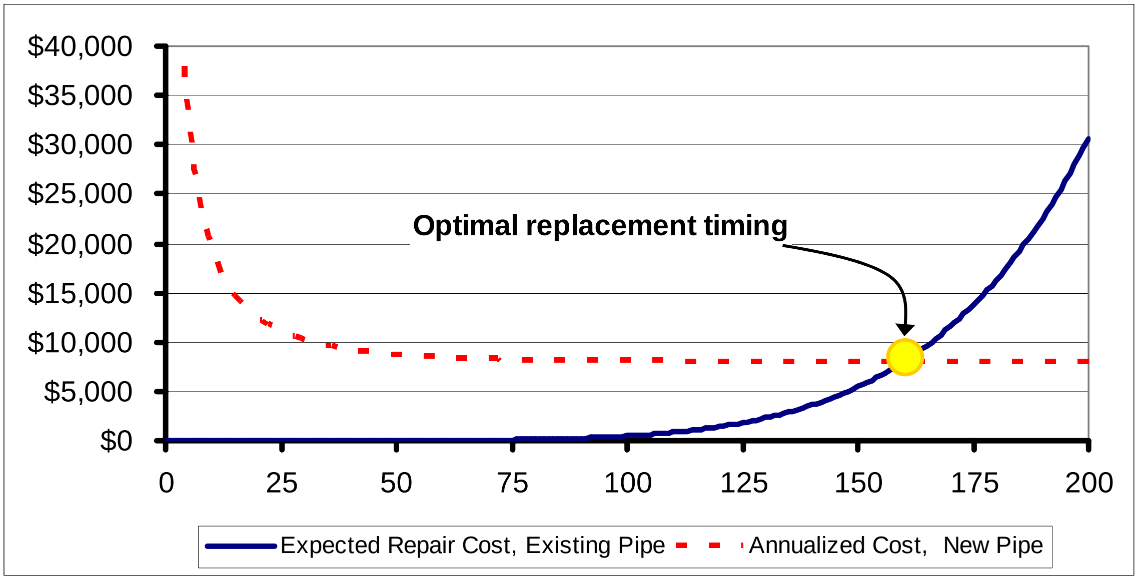


Figure 2. Optimization of Replacement Timing

In recent years, the Pipe Replacement Model has justified approximately $1-2 million of annual spending on pipe replacement. The corresponding pipe reactive costs have been approximately $1 million annually. The Pipe Replacement Model is described in more detail in Appendix C – Pipe Replacement Model Document.

Opportunity Model and Fire Flow Improvement Considerations

There are numerous opportunities for SPU to take advantage of an upcoming project to replace an existing asset at a reduced cost, by coupling outages or combining projects to reduce mobilization cost or street pavement restoration costs, for example. This is advantageous if the cost saved is greater than the expected cost of moving the timing of one project to match the other (i.e., replacing one pipe too early or too late). The Opportunity Model provides SPU with a tool to make these decisions in a consistent manner, by comparing the opportunity cost versus the normal replacement costs to determine whether the project is justified or not.

Other Programs

SPU is conducting a pilot cleaning and lining program in 2005 covering approximately 19,000 linear feet of unlined, cast iron pipe in the Ballard area. The project is expected to provide improved water quality, more flow, increased pressure, and added pipeline life while minimizing disruption to the community at a third of the cost of pipeline replacement. If successful, the program will continue to re-line more of the 700 miles of unlined, cast iron pipe in the SPU system.

Benchmarking of Replacement Planning Strategies

The survey submitted to comparable utilities included questions about methods of long-range planning and leakage and outage targets. Most utilities knew how many failures they had experienced in the recent past, however none in the US had systematic projection of future system performance, and few had explicit targets for system performance such as number of customer outages.

Of the utilities surveyed, Portland Water Bureau and Denver Water Department appeared to have more systematic methodologies for prioritizing their short-term replacement programs. Both utilities had scoring systems for ranking pipe replacement activities based on factors such as leakage history, water quality impacts, fire flow availability, and other relevant factors.

Much of SPU's replacement planning methodology came about due to its asset management program, developed in partnership with Hunter Water from Australia. Asset management principles emphasize the rigorous evaluation of spending programs and tying performance targets directly to spending. These principles emphasize life cycle cost analysis to determine the appropriate time to replace a pipe instead of traditional decision processes that are solely based on age or a prescribed percent replacement of the system. This shift in methodology is being supported by field investigations and data collection by comparable utilities.

System Leakage

Water systems such as SPU's will soon be required to meet a Washington State Department of Health (DOH) standard to minimize loss of water from leakage within its distribution system. The DOH draft rule, found in Chapter 246-290 of the Washington Administrative Code (WAC) will require water systems with greater than 10,000 connections to maintain water system leakage to less than 10 percent unless achieving that limitation is not technically feasible. This section summarizes the leakage projections, based on SPU's long-range replacement program. Appendix D – Leakage Projection Memo contains a complete description of the methodology and results.

Leakage Categories and Sources

The International Water Association (IWA) categorizes leaks in municipal water systems as follows:

- *Background (i.e., undetectable) leakage*. Background leakage is too small to be detected through modern sonic leak detection methods. It often occurs through the joints of pipes, and can be quantified through nighttime flow analyses. Measures to control background leakage are generally operational, focused on pressure management in the distribution system.

- *Reported leaks and breaks* are usually the best-documented leaks. Reported leaks typically have high flows but last for a shorter duration (3 to 7 days) than background leaks, since they generate the highest level of response.
- *Unreported leaks and breaks* can be detected through modern sonic leak detection methods. Without proactive programs to detect these leaks, however, they often go unnoticed for long periods of time. Unreported leaks typically have lower flows than reported leaks, but due to their longer duration, they often account for a larger total volume of water loss. Unreported leaks from water mains (generally in the public right-of-way) and those in service connections are considered separately in reporting and estimating leakage.

System Leak History

SPU has been collecting data on the reported water main leaks and breaks that occur within its system each year. Although data prior to 1990 was available, only 1990-2005 data on leaks was used for the analysis to ensure consistent data quality and uniform data collection methods. That data can be broken down by month, by pipe type, by leak/break type, and by size. The data also includes an estimate of the repair cost for each leak based on pipe type. Figure 5 displays average annual numbers for reported leaks. For the last 15 years, SPU has averaged approximately 150 reported leaks/breaks per year. For the last 4 years, SPU has averaged approximately 130 reported leaks/breaks per year.

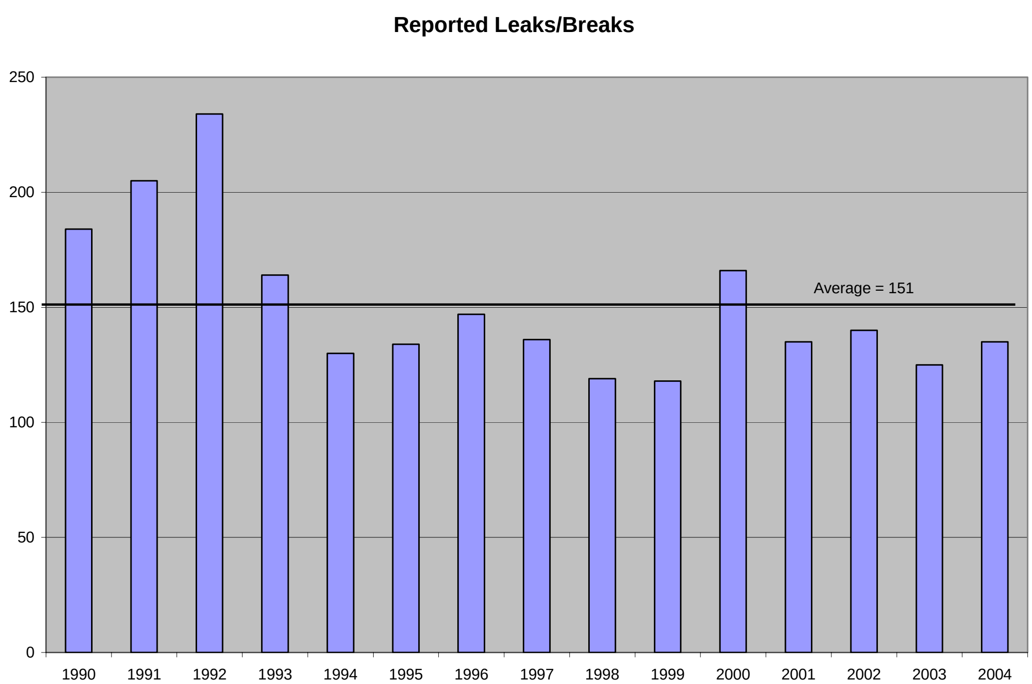


Figure 5 – Annual Water Main Leaks and Breaks Reported by SPU

SPU also collects data on service connection leaks and breaks for each pipe type. There are over 55,000 service connections composed of non-copper materials including plastic, galvanized steel, ductile and cast iron, and other materials. Of these service connections, 30,000 are plastic, which have leakage rates that are approximately four times as high as copper service connections. Through a proactive replacement program, SPU plans to replace all of its plastic, galvanized, ductile/cast iron, and other/unknown material service connections with copper connections by 2015. This replacement program is expected to reduce the service connection leakage rate from an average of 2.8 to 1.5 leaks/1000 services.

Current Programs to Quantify and Reduce Leakage

SPU is currently implementing several programs to help quantify and reduce leakage throughout the system. As mentioned in the previous section, SPU is implementing a proactive replacement program to replace plastic, galvanized, ductile/cast iron, and other/ unknown material service connections, which have high leakage rates, with copper connections, which have leakage rates that are substantially lower. In addition, SPU has programs to ensure the accuracy of source meters and billing meters, which are used to determine overall non-revenue water quantities for the water system. Finally, SPU currently conducts leakage test at reservoirs and is in the process of installing flow measurement devices to measure reservoir overflows. These activities are intended to help reduce the total volume of water loss from reservoirs.

Benchmarking System Leak Rate

The agency surveys included questions about system leakage, which allows SPU to compare its leakage rate against other utilities'. Figure 6 below shows this comparison. The leak rates have normalized by the length of pipe in each system, and they are shown for each year for which data were provided.

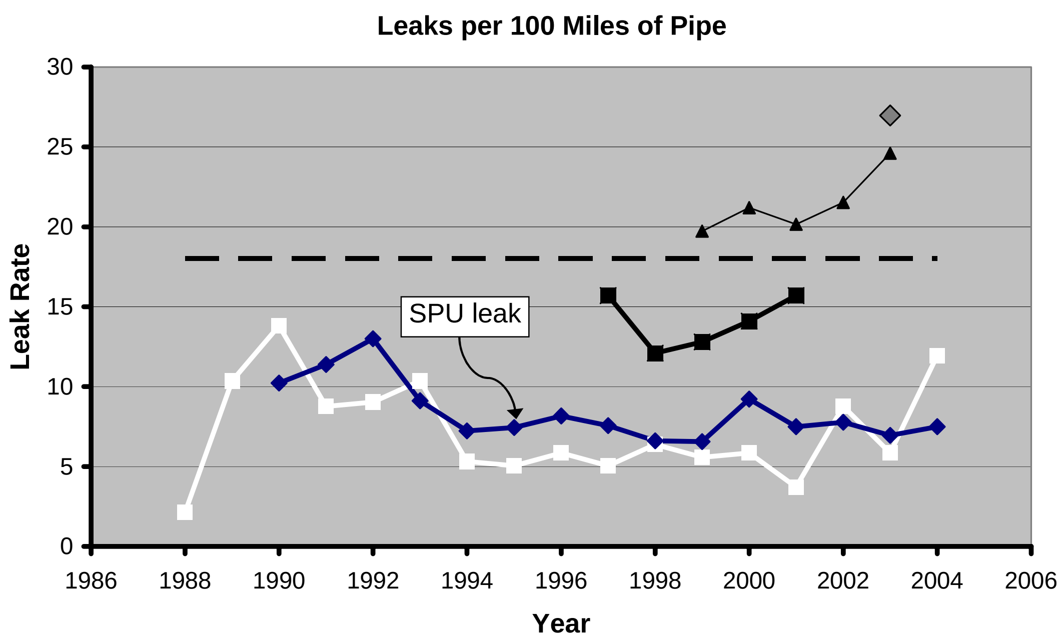


Figure 6 – Comparison of SPU Leak Rate with Other Utilities'

Not shown in the figure is the leak rate reported from one utility of about 160 leaks per 100 miles, about five times higher than any other. As stated above, SPU currently experiences 151 leaks per year, or 8.4 leaks per 100 miles of main. The leakage rates of other agencies vary significantly. Overall, the leakage rate for SPU is lower even though the system is older than other utilities'. However, EBMUD has performed a study that concluded that no correlation between system age and leakage rates exists within their system, which suggests that the relatively good leak performance of SPU's system may be related to factors other than its age and further supports SPU's approach of using more sophisticated water main replacement models to determine when to replace pipes.

Estimating Current Leakage

SPU's existing system leakage from pipes was estimated in the 2001 Water System Plan to be as high as 5.7 million gallons per day (mgd). This value was based on quantification of SPU's non-revenue water. Recent system investigation has revealed that 5.7 mgd is more likely to be an upper limit of current system leakage. In an attempt to better quantify the current leakage rate, Brown and Caldwell used three methods to estimate current leakage within the system. The three methods provided a low, middle, and high estimate for leakage, based on a methodology similar to the IWA Unavoidable Real Losses (UARL) calculation for estimating leakage. Appendix D provides a detailed explanation of the calculations used to estimate the current leakage rates.

Table 1 shows the results of the three methods in terms of total leakage from both mains and service connections. The current leakage from SPU's system is estimated between 3.3 mgd and 4.8 mgd, or less than 4% of the current 128 mgd production.

Table 1. Estimated System Leakage

Method	Total Leakage
Low Estimate	3.3 mgd
Middle Estimate	4.1 mgd
High Estimate	4.8 mgd

Projected Future Increases in Leakage

As described in the previous section, three different methods were used to calculate current leakage volumes. In order to project future leakage volumes, assumptions were made on how reported, unreported, and background leakage rates would increase for both service connections and mains. Those assumptions were as follows:

- Reported leaks and breaks on mains will increase as projected by Waverider. As discussed earlier, SPU currently experiences 151 reported breaks a year in its water mains. Waverider projects that the number of reported leaks and breaks in water mains will increase to 3,882 breaks in 2095.
- Unreported leaks and breaks on mains will increase in proportion to reported leaks and breaks.
- Background leakage on mains will increase in proportion to the average age of SPU's water mains

- Reported leaks and breaks on service connections will increase or decrease as shown in Figure 7 below. The reasoning behind this profile is explained in Appendix D.
- Unreported leaks and breaks and background leakage on service connections will increase or decrease in proportion to the reported leaks and breaks on service connections.

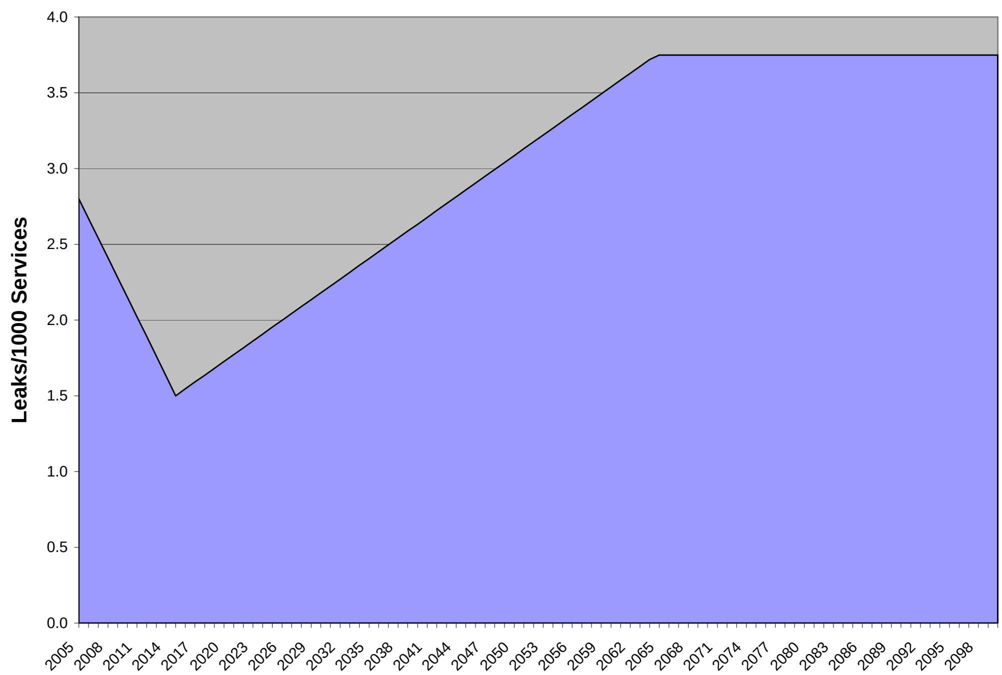


Figure 7 – Projected Service Connection Leakage Rates over Time

The quantity of water lost due to leakage was projected into the future using the same three methods used to estimate the current level of leakage. Table 2 below summarizes the results of these calculations, showing the estimated leakage now and the projected leakage in 2095. The year 2095 was chosen because this is projected to be the year at which the system leakage peaks, and after which it begins to decline as the rate of pipe replacement increases. The table also shows whether the projected leakage is expected to exceed the 10% limit established by DOH. Current demand forecasts from 2006 through 2060 were used to calculate the percentage of water loss in future years. It was assumed that the billed water demand and non-revenue water demand not including leakage would follow the forecast until 2060, and then remain constant from 2060 through 2100.

Table 2. Projected System Leakage

Method	Current Leakage	Projected in 2095	Exceeds 10% limit?
Low Estimate	3.3 mgd	9.1 mgd	No
Middle Estimate	4.1 mgd	12.4 mgd	No
High Estimate	4.8 mgd	15.7 mgd	No

The table indicates that the system leakage is not expected to exceed DOH's 10% maximum leakage standard even with the highest leakage projections. Appendix D provides a more detailed explanation of the methodology used to project the future system leakage rates.

OUTAGE PROJECTIONS

Water outages, where customers are without potable water for a period of time, can be caused by both planned and unplanned activities. For example, a utility may plan to replace a pipe and inform its customers that they will receive an outage for certain length of time on a specified date. On the other hand, a water pipe may unexpectedly fail, and the repair activities necessary to fix the pipeline may result in water having to be shut off to a number of customers. SPU has a water outage service level target that fewer than 4 percent of retail customers will experience water outages for one or more events totaling more than 4 hours per year. Assuming that the number of customer services remains constant at 180,000, this would translate to 7200 services. While SPU is currently well within the 4 percent target, it is important to determine whether the planned replacement program will also meet the service level.

The Outage Projection Memo in Appendix E describes in detail the methodology for estimating the effect of SPU's water main rehabilitation program on customer water outages system-wide over the next 100 years.

Current Outage Rates

SPU collects data on system outages, including frequency, cause, duration, and number of customers affected. Table 3 provides a summary of the causes, the average annual number, and the number of services affected on average by outages greater than 4 hours in duration.

Table 3. Characterization of Outages Greater Than 4 Hours in Duration

Outage Cause	Current Average Number of Outages > 4 hours Per Year	Current Average Number of Services Affected by Outages > 4 hours Per Year
Main Leaks/Breaks	15	236
Planned Pipe Replacement	4	120
New Water Main Installations, Relocations	34	1020
Miscellaneous (e.g., broken service connections, new service connections, repairs/replacements of valves, fire hydrants, corporation stops, water meters, etc.)	33	685
Total:	**86**	**2061**

The current average total number of services affected by outages greater than 4 hours per year is approximately 2061 services.

Projection of Future Outage Rates

The future number of services affected by outages totaling more than four hours per year was projected to determine whether the service level target will continue to be met with SPU's long-range pipe replacement program. The first step was to project the future number of outages from the projected number of water main failures and replacements. The second step was to project the number of services affected by those outages. It was assumed that outages caused by main leaks/breaks and planned pipe replacements would increase according to the Waverider projections, while outages caused by all other causes (new water main installations, relocations, broken service connections, repairs/replacements of valves, etc.) would stay constant at the current levels. The complete methodology for projecting future outage rates is described in detail in Appendix E.

Figure 8 below shows the projected number of services affected by outages of greater than four hours in each year for the next 100 years. The target maximum is 4%, which represents the 7200 services if 180,000 total customers are assumed. The figure indicates that this target will be exceeded in 2052, so SPU has approximately 45 years before the target is exceeded. This allows time to calibrate the assumptions, gather additional information, and assess needed changes. Other possible strategies to avoid exceeding the target include:

- Increasing system redundancy through additional line valves or looping to limit the number of services affected by an outage.
- Using temporary lines during planned events.
- Throttling valves instead of shutting them completely off to allow some water service during repairs.
- Reducing the duration and/or number of services impacted by shut-offs for planned events.
- Raising the outage target based on customer willingness to pay surveys.
- Revising the service level target to distinguish between planned and unplanned outages.

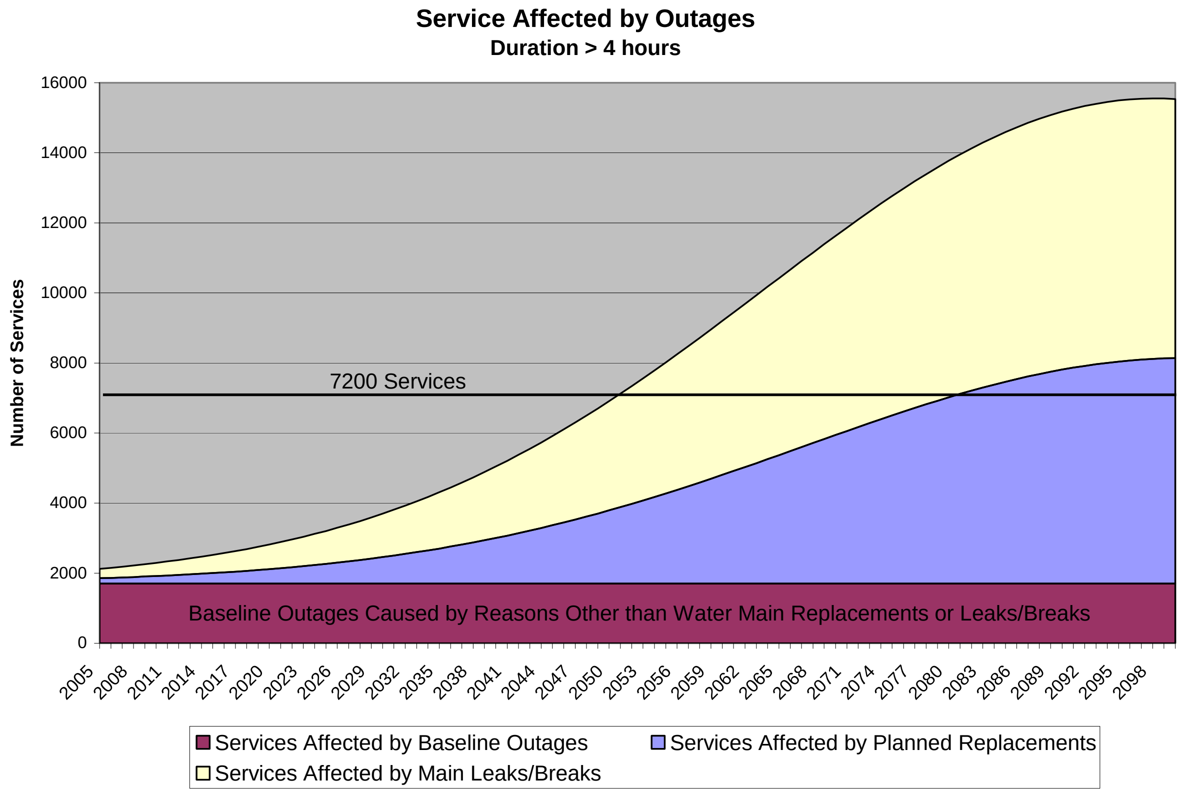


Figure 8 – Projected Number of Services Affected by Outages Greater than 4 Hours

WORKFORCE PLANNING

Leak repairs are expected to increase gradually over several decades. By 2050, the number of repairs is expected to be approximately ten times the current level. SPU plans to meet this increased work load demand through a combination of in-house crews and outside contracting. From present, SPU has at least 10 years before any significant increase will be seen, and SPU plans to manage this modest workload increase with current staffing. Over the next 10 years, SPU will have sufficient time to plan for the future workforce requirements while simultaneously continuing their efforts of monitoring and data gathering to refine forecasts of workforce needs as the expected growth in repairs approaches.

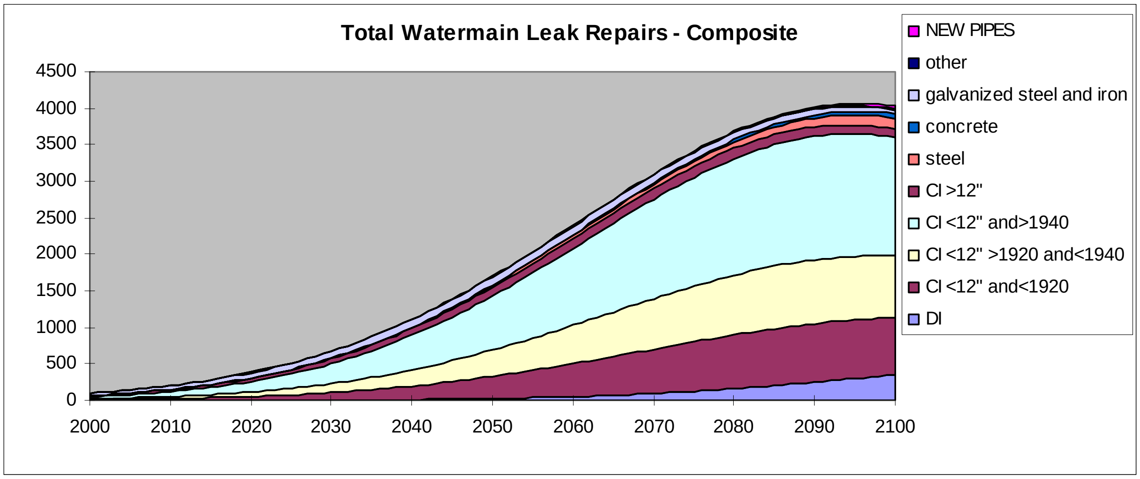
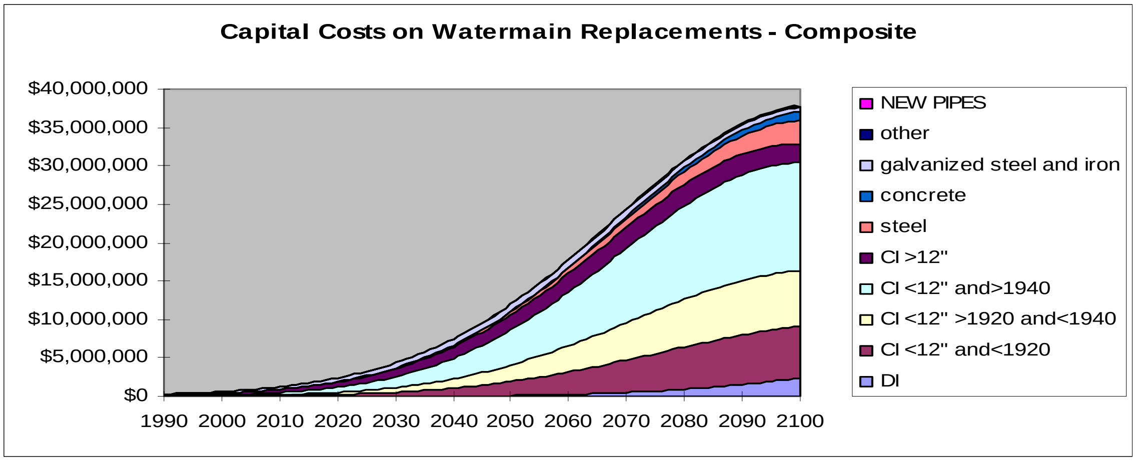


Table 4. Number of Projected Leaks

Year	Number of Leak Repairs
2005	151
2010	203
2015	280
2020	381
2025	510
2030	673
2040	1111
2050	1699
2060	2395
2070	3099
2080	3676
2090	4001
2100	4005

FINANCIAL PLANNING

Expenditures for leak repairs and water main replacement will increase gradually over several decades. By 2050, the financial requirements of the water main replacement/repair program will be approximately ten times greater than current levels. SPU plans to meet the growing financial demands through a combination of debt financing and rate funding. Since the financial needs are not expected to increase significantly over the next 10 years, SPU plans to manage the modest increases in revenue requirements with little impact. SPU plans to develop a more concrete plan for meeting future financial requirements during this 10 year timeframe, while simultaneously monitoring and gathering additional data to further refine forecasts of financial needs.



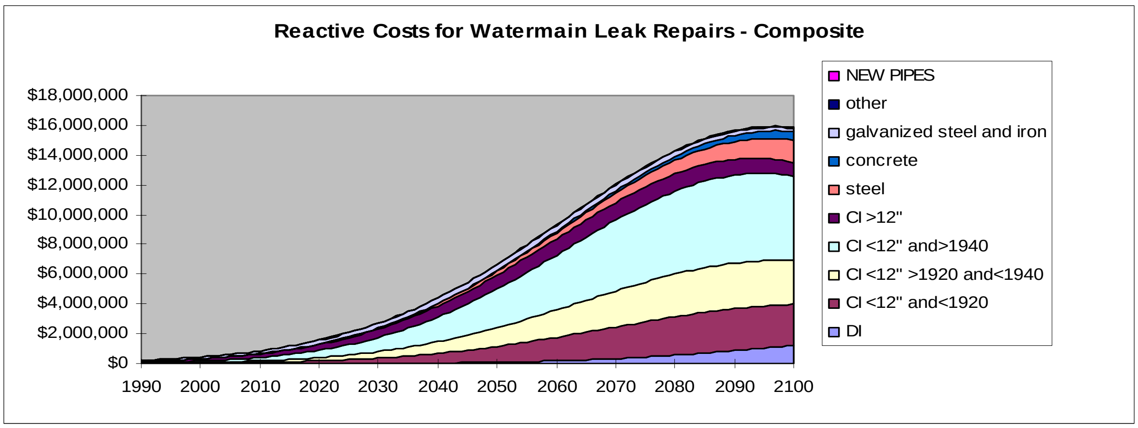


Table 5. Projected Expenditures

Year	Expenditures on Main Replacement	Expenditures on Leak Repairs
2005	$875,000	$617,000
2010	$1,240,000	$854,000
2015	$1,730,000	$1,165,000
2020	$2,388,000	$1,570,000
2025	$3,251,000	$2,083,000
2030	$4,364,000	$2,721,000
2040	$7,498,000	$4,417,000
2050	$12,015,000	$6,670,000
2060	$17,838,000	$9,322,000
2070	$24,414,000	$12,020,000
2080	$30,724,000	$14,283,000
2090	$35,545,000	$15,656,000
2100	$37,903,000	$15,886,000

FUTURE DATA COLLECTION AND OTHER IMPROVEMENTS

SPU has identified the following areas where improved data collection or other improvements can increase the precision and accuracy of the results on which the replacement program is based.

- Add Social/Environmental Costs from Pipeline Replacement Model in Waverider. Currently, the pipe-replacement model includes consideration of non-dollar costs from pipe failure or replacement. These include the effects of an outage on customers, traffic effects, and potential fire effects. However, these costs are not included in Waverider. It is not clear what affect this has on Waverider's projection of future reactive costs.
- Collect data to support failure probability curves used in Waverider and Pipe Replacement Model. Currently, the failure curves used in these models are based on standardized curves rather than on SPU's own data. Over time, these data can be collected, and the curves can be customized to SPU.
- Continue to investigate methods of determining customer costs from outage. This can be used to support the calculations in the Pipe Replacement Model, as well as the outage service-level target.
- If SPU observes that system leakage is approaching the DOH 10% leakage standard, then SPU should consider making additional efforts to better quantify existing system leakage, characterize the sources of leakage, and implement control measures to ensure that the DOH leakage standard is not violated. These efforts may include more detailed water audits, night time flow assessments, and/or inspections.
- Consider revising the service level for outages to distinguish between planned and unplanned outages. Generally speaking, customers are more tolerant of outages when they have advance notice of one. Customer surveys, including willingness to pay information, should be used in revising the service level.

CONCLUSIONS

In conclusion, the current SPU water system rehabilitation and replacement strategy provides a high level of service at the lowest life cycle cost. SPU has made significant efforts to include social and environmental costs as well as direct costs in the decision framework. It does not appear that the current strategy will have a substantial impact on system leakage and outage rates in the immediate future (i.e., next 10 years), and therefore immediate mitigation steps are not necessary at this time. It is recommended that SPU continue their efforts towards monitoring the results of the replacement program and gathering additional data to refine their analyses and projections, and mitigation steps should be developed should leakage and outage rates increase at higher than expected rates. Finally, SPU should continue their efforts towards workforce and financial planning as they prepare for increases in the workforce and revenue requirements in the next 30-50 years.

Appendices

A Agency Surveys
B Waverider Document
C Pipeline Replacement Model Document
D Leakage Projection Memo
E Outage Projection Memo

APPENDIX A
Agency Surveys

General System Background

1. System Name: East Bay Municipal Utility District

2. Designated Contact Person and Title: William R. Kirkpatrick, Engineering Manager of Water Distribution Planning Division

3. Retail Service Connections:, 379,672 potable connections, plus 5,698 fire services (as of June 2005)

4. 2004 Total Service Population: Approximately 1.3 million customers

5. Wholesale Service Connections: zero

6. Lineal feet of Retail Service Mains: 21,481,634 feet (4,068 miles)

Tracking Outages and Leakage Service Levels

1. How are outage and leakage rates tracked at your utility? Are there data that we can see? We are particularly interested in summary data and trending of both outage metrics and leakage rates.

EBMUD tracks unplanned shutdowns on a web-based system including information on main size, outage duration, and the number of water services affected. The summary data are reported for unplanned shutdowns on water mains smaller than 12-inches in diameter. Here's an example of the outage data available:

Unplanned Outages Performance Measures

- There were 225 unplanned shutdowns on mains <12 inches between July 1, 2005 and September 30, 2005.
- 65.3 percent were less than four hours (34.7 percent four hours or greater). Of the same shutdowns, 143 (63.6 percent) affected less than 25 services (leaving 36.4 percent 25 services or greater).
- If the shutdown affected more than one pipe, it was counted only once.

EBMUD tracks pipe leaks by date, location and severity. The leak history of a pipeline is captured in a web-based application, which includes the existing pipeline information and potential pipeline replacement candidates. Additionally, leak rate is tracked through a centralized database.

2. Describe the age profile of your system. What percentage (approximately) was installed before 1950, 1975, and 1990?

Attached is a current pipeline inventory on the miles of pipe by material type and age. The percentage of pipelines installed before 1950 is about 32 percent; before 1975 is about 73 percent; and before 1990 is about 90 percent.

3. Do you track outage rates and leakage versus system age?

Yes, but we have determined that pipe age is not a significant factor impacting leak rates. The goal of EBMUD's pipe replacement program is to replace pipe when replacement is more cost effective compared to continued maintenance.

The leak history of a pipeline is tracked and the assumption is made that the pipe will continue to experience breaks at a rate equal to the average over the last five years of break history. If this rate is above average, we perform the economic analysis. Segments with two leaks in 500 linear feet or 3 leaks in 1,000 linear feet are selected for analysis. If not, there is no further action. The cost of break repair is an average of total cost to repair all breaks divided by total number of leaks. The break repair cost is updated every year. Break repair costs are projected into the future at the current five-year break rate on a present worth basis. Other factors are looked at such as seismic hazards, soil conditions, collateral damage, customer service, water quality maintenance, and these costs, if any, are added in. This gives us "Cost" to continue to repair the pipeline, which is compared to the cost to replace the pipeline. We use a standardized average cost per foot to replace cast iron with steel or PVC using an open cut trench excavation process to estimate this potential "Benefit" to replace versus continue to repair. The Cost/Benefit ratios for pipelines are grouped into three categories by their ratios:

- Watch list 1.0 < # < 1.4
- Low priority 1.4 < # < 1.7
- High priority 1.7 < #

Several other factors are then used to prioritize and select candidates for design and construction.

a) Potential for high collateral damage or costly outages to large industrial users.
b) Coordination of replacement work with street paving projects by cities and counties (about 30 percent of all designs done for infrastructure renewal in recent years). This is an important consideration, not just because of the benefits and good will from this type of coordination, but also to avoid the costs of trench cut fees that are now being assessed if you need to cut into a newly repaved street.
c) Clustering replacements (multiple job packages in same area) for improved construction efficiency as well as a desire to replace candidates with the highest cost/comp ratios first.
d) The ability to satisfy parallel needs such as inadequate flow area or single feed reliability issues.
e) Water quality problems
f) Other factors such as seismic fault zone, soil movement area, damage potential, corrosive soils, customer complaints, etc., also influence selection for design.

4. Have outage levels or leakage rates changed over time? If so, in what way, and why?

EBMUD has found the leakage has been holding relatively constant at about 750 to 850 leaks per year for the past 23 years, or about 18 breaks per 100 miles (see attached chart – Figure 5.2).

The number of unplanned pipeline segment shutdowns has remained flat; the average is 1,064 shutdowns annually with a range of 980-1,156.

5. Have you projected your system's performance into the future? Do you expect it to improve or deteriorate over the next 10 years? The next 20?

Yes, EBMUD has developed a model to forecast system performance into the future. Based on this statistical model, past experience, and based on a replacement rate of approximately 5 to 6 miles of cast iron pipe per year, we project our leak rate to remain fairly constant in the next 10 to 20 years.

To forecast failure rates for our cast iron pipes, EBMUD developed a Long Term Predictive Model (LTPM) that is based on work by AWWARF. This LTPM was used to predict future trends in the leak rate for cast iron pipe that would result from a variety of pipeline renewal strategies. EBMUD's LTPM is based on District-wide leak data and historical data for selected base maps. In order to analyze the effect of pipeline renewal activities on future leak rates, a computer time-step model was developed that uses a mathematical model to predict the time-to-failure for each pipe in the system. The model then progressed from year 1997 to year 2050, tallying leaks from pipes not yet replaced. The LTPM was used to study how the leak rate would perform as a function of pipe renewal rates. This analysis indicated that over the next 10-15 years, approximately 5-6 miles/year of well targeted cast iron pipe renewals is necessary to avoid increases in our leak rate.

It should be noted that EBMUD's LTPM required important data management assumptions regarding geographic coefficients, life expectancy of cast iron, failure mode, affects of corrosion protection measures, etc. The results of EBMUD's LTPM are therefore not absolute, the various factors are best judgment estimates.

6. Are there targets for level of service established for these categories? Are your utility's targets established by the regulator or internally? If internally, how are they established; if by the regulator, how do you decide whether to go beyond the minimum targets (if you consider it)?

Yes, these targets are established internally. For outages, EBMUD tracks the number of unplanned outages versus duration and whether the outage impacted 25 or fewer customers versus greater than 25 customers. This is a performance indicator used in determining the Maintenance Department's performance and is periodically reviewed to ensure it is meaningful.

General System Background

7. System Name: Denver Water

8. Designated Contact Person and Title: Andrew Appell, General Planning

9. Retail Service Connections: Number of accounts = 221,627

10. 2004 Total Service Population: 1,104,000

11. Wholesale Service Connections: 75,629

12. 2,608 miles of pipe in system

Tracking Outages and Leakage Service Levels

1. ***How are outage and leakage rates tracked at your utility? Are there data that we can see? We are particularly interested in summary data and trending of both outage metrics and leakage rates.***

   We do track leak rates (12" & smaller pipe only) once a year. Following are those leak rates for the last 8 years.

   1997 - .157 leaks/mile
   1998 - .121 leaks/mile
   1999 - .128 leaks/mile
   2000 - .141 leaks/mile
   2001 - .157 leaks/mile
   2002 - .183 leaks/mile
   2003 - .137 leaks/mile
   2004 - .127 leaks/mile

   8 year average - .143 leaks/mile

   Such things as weather conditions, pipe replacement rates, and soil conditions have effects on yearly leak rates.

2. ***Describe the age profile of your system.*** What percentage (approximately) was installed before 1950, 1975, and 1990? By pipe length, 25%, 58%, 80%

3. ***Do you track outage rates and leakage versus system age?*** No, but we do keep track of the age of pipes to determine when they will need to be replaced.

4. ***Have outage levels or leakage rates changed over time?*** If so, in what way, and why?

5. ***Have you projected your system's performance into the future? Do you expect it to improve or deteriorate over the next 10 years? The next 20?*** Yes, we evaluate the system into the future using modeling, and we plan for facilities to ensure we can maintain our standards for service. We do expect that the system will continue to age, as our main replacement program does not replace enough pipe per year to keep up with the aging of the system.

6. ***Are targets for level of service established for these categories? Are your utility's targets established by the regulator or internally? If internally, how are they established; if by the regulator, how do you decide whether to go beyond the minimum targets (if you consider it)?*** There is no external regulator. But if two leaks occur within the same pipe in one year we will take a look at it and decide whether it needs to be replaced. We have found it is cheaper in the long run to replace a leaking pipe rather than trying to fix it. If you have any further questions about leakages or outages please contact Ricky Corbin (Engineering Specialist) at 303-628-6622 or ricky.corbin@denverwater.org

1.System Name: Los Angeles Department of Water and Power

*2.*Designated Contact Person and Title: Albert G. Gastelum

*3.*Retail Service Population: 3.9 million

4.Retail Service Connections: 708,250

5.Wholesale Service Population: none

6.Wholesale Service Connections: none

*7.*Lineal Feet of Retail Service Mains: 7,300 miles

8.Lineal Feet of Wholesale Transmission Mains: none

Tracking Outages and Leakage Service Levels

9.***How are outage and leakage rates tracked at your utility?*** By use of our work-management system, SCADA, CIS and GIS systems, key-indicator(work load) metrics and goals, Engineering Section reports . ***Are there data that we can see?*** *No* ***We are particularly interested in summary data and trending of both outage metrics and leakage rates.*** *(blowouts = anything that creates more than 100 sf of street damage)*

10. ***Describe the age profile of your system.*** What percentage (approximately) was installed before 1950 *(42%),* 1975 *(83%),* and 1990 *(91%)*?

11. ***Do you track outage rates and leakage versus system age?*** *Data can be queried to produce this info.*
Fiscal 99-00, Leaks = 1486, Blowouts = 208, Service Leaks = 3129 (at the meter)
Leaks per 100 miles, 23 leaks per 100 miles

Fiscal year 00-01, 1660 leaks, 161 blowouts, 2644 service leaks
25 per 100 miles

Fiscal 01-02, 1589 leaks, 142 blowouts, 2730 service leaks
24 per 100 miles

Fiscal 02-03, 1624 leaks, 225 blowouts, 2771 service leaks
25 per 100 miles

Fiscal 03-04, 1908 leaks, 206 blowouts, 2701 service leaks
29 per 100 miles

12. ***Have outage levels or leakage rates changed over time? Number of leaks per year has been steady. If so, in what way, and why?***

    85% of the leaks/blowouts will require some type of outage. Some cases short outage (less than an hour). Up to 8 hour (sidelines, temporary corrections). More than ¾ of the leaks/breaks have some sort of outage.

13. ***Have you projected your system's performance into the future?*** Somewhat, but not in a single comprehensive study. ***Do you expect it to improve or deteriorate over the next 10 years?*** As part of our overall capital improvement program, we're currently pursuing an infrastructure replacement program,focused on our large trunklines as well as routine mainline replacement. The next 20?

14. ***Are targets for level of service established for these categories?*** An internally imposed target is 4 leaks per 1,000 lineal foot stretch of pipe before replacement is considered. ***Are your utility's targets established by the regulator or internally? If internally, how are they established; if by the regulator, how do you decide whether to go beyond the minimum targets (if you consider it)?*** *Established based on historical experience.*

    4 leaks per 1000 lineal foot of stretch is the time when the pipeline should be replaced. There was probably an economic basis back then.

    Maintenance cost per lineal foot = look at that.

    There is a goal for outages (people out of water) per month. (metrics) service reliability.

General System Background

1. System Name: Philadelphia Water Department

2. Designated Contact Person and Title: George Kunkel, Assistant Chief Water Conveyance Section

3. Retail Service Population: approximately 1.5 million

4. Retail Service Connections: approximately 480,000 connections

5. Wholesale Service Population: approximately 250,000 million

6. Wholesale Service Connections: 3 sizable connections (some other minor, standby connections), wholesale to other neighboring water suppliers, 2 customers

7. Lineal Feet of Retail Service Mains: 3800 miles of pipeline

8. Lineal Feet of Wholesale Transmission Mains: (16” above)

Tracking Outages and Leakage Service Levels

9. ***How are outage and leakage rates tracked at your utility? Are there data that we can see? We are particularly interested in summary data and trending of both outage metrics and leakage rates.***

   Structure out from the IWA (International Water Association). Reported vs. Unreported leaks. In Philadelphia, information management system does not have a better definition system in use.

   SPU is part of a leakage management program with AWWA. Philadelphia does a pretty comprehensive water audit every year. In Water Stats 2002 Distribution System Survey, AWWA did a very large survey was on distribution systems.

10. ***Describe the age profile of your system. What percentage (approximately) was installed before 1950, 1975, and 1990?***

11. ***Do you track outage rates and leakage versus system age?***

    Case by case, not systematically. Picked up on trends, certain pipes, certain vintages have higher failure rates.

12. ***Have outage levels or leakage rates changed over time? If so, in what way, and why?***

Leakage rates – auditing approach (water put in, water customers register), apparent losses, physical losses.

Can do nightflow analysis. Can do a component analysis, looks at detail leakage records and findings (what are the events, what types of events, leakage rates, pipes, what is the response time.) – can build up what the leakage would be.

Physical real losses – cut the total non-revenue water by one-third in the past 11 years.

13. ***Have you projected your system's performance into the future? Do you expect it to improve or deteriorate over the next 10 years? The next 20?***

14. ***Are targets for level of service established for these categories? Are your utility's targets established by the regulator or internally? If internally, how are they established; if by the regulator, how do you decide whether to go beyond the minimum targets (if you consider it)?***

    Approximate target (internal to the City): conservative target. Survey (1/3 of the system) by sound testing, very proactive leak detection program.

General System Background

1. System Name: Portland Water Bureau system
2. Designated Contact Person and Title: Stan Vandebergh, Dave Evonuk
3. Retail Service Population: ~550,000
4. Retail Service Connections: 180,000
5. Wholesale Service Population: ~250,000 – 300,000
6. Wholesale Service Connections: ~20
7. Lineal Feet of Retail Service Mains: 2,100 – 2,200 miles distribution system piping
8. Lineal Feet of Wholesale Transmission Mains:

Tracking Outages and Leakage Service Levels

9. ***How are outage and leakage rates tracked at your utility? Are there data that we can see? We are particularly interested in summary data and trending of both outage metrics and leakage rates.***

   (Ask Jeff Leighton) Leakage study done on a large part of the system. Tracked reservoirs dropping to estimate leakage.

10. ***Describe the age profile of your system. What percentage (approximately) was installed before 1950, 1975, and 1990?***
11. ***Do you track outage rates and leakage versus system age?***
12. ***Have outage levels or leakage rates changed over time? If so, in what way, and why?***
13. ***Have you projected your system's performance into the future? Do you expect it to improve or deteriorate over the next 10 years? The next 20?***
14. ***Are targets for level of service established for these categories? Are your utility's targets established by the regulator or internally? If internally, how are they established; if by the regulator, how do you decide whether to go beyond the minimum targets (if you consider it)?***

General System Background

1. System Name: City of Vancouver
2. Designated Contact Person and Title: **Norm Kramm, Ops Superintendent**
3. Retail Service Population: **170,056**
4. Retail Service Connections: **63,298**
5. Wholesale Service Population: **None**
6. Wholesale Service Connections: **none**
7. Lineal Feet of Retail Service Mains: **851 miles**
8. Lineal Feet of Wholesale Transmission Mains: **None**

Tracking Outages and Leakage Service Levels

9. ***How are outage and leakage rates tracked at your utility? Are there data that we can see? We are particularly interested in summary data and trending of both outage metrics and leakage rates.*** The Water Operations group, managed by Don Lawry, performs leak surveys to track lost water. You can call him directly at 360-696-8243 to find out the exact details of their program. (e-mail at Don.Lawry@ci.vancouver.wa.us)

10. ***Describe the age profile of your system. What percentage (approximately) was installed before 1950, 1975, and 1990? Don*** Lawry may have something on this, but Eng. Does not have a current profile on pipeline age on hand that I can transmit to you……..

11. ***Do you track outage rates and leakage versus system age*?** I am not aware of nor have never seen a record of this. However if you write to Don Lawry directly, you might ask him if he is aware of anything.

12. ***Have outage levels or leakage rates changed over time? If so, in what way, and why?*** I know they have gone down – the actual numbers are in the range of water lost was above 10% and is currently around or below 5%....I do not have data readily available for outages….

13. ***Have you projected your system's performance into the future? Do you expect it to improve or deteriorate over the next 10 years? The next 20?*** The current master planning cycle is based upon meeting WAC criteria for maintaining current service levels and improving system performance as needs are identified. We will set project priorities and request funding in order to maintain or improve above current levels of services…….

14. ***Are targets for level of service established for these categories? Are your utility's targets established by the regulator or internally? If internally, how are they established; if by the regulator, how do you decide whether to go beyond the minimum targets (if you consider it)?*** Current practice is to install an 8" DI (minimum) everywhere a hydrant is supplied, to target fireflows of roughly 1,000 gpm in residential areas, 2000 in commercial and 2500 in industrial zones.

APPENDIX B
Waverider Document

BROWN AND CALDWELL

Technical Memorandum

Seattle Public Utilities
Water Plan Update (28901)
Task 7 – Distribution System Renewal Strategy

Date: November 2005

To: Bill Wells, SPU
Jon Shimada, SPU
Tim Skeel, SPU

From: Darin Johnson, BC

Copy to: Andrew Lee, BC
Corinne DeLeon, BC
Scott Anschell, BC
File

RE: Waverider Model

General description of model

Intent of pipe replacement model

Seattle Public Utilities has over 1,800 miles of water pipe in their system, representing a capital replacement value of nearly $3.5 billion. SPU uses a life cycle cost-based model called Waverider for planning its long-range pipe replacement program. Waverider is an economic model that balances the cost of ongoing pipe repair as pipes age, against the cost of pipe replacement in order to forecast long range CIP and O&M funding needs for the water pipe assets. In addition to quantifying the long run costs of pipe repair and replacement Waverider projects the number of leak repairs and the miles of pipe replaced each year by class of pipe. The economic life of a pipe is defined as the replacement age that minimizes life cycle cost, in other words, the end of economic life is determined by the optimal balance between repair cost and replacement cost.

The replacement program is based on the expected economic life of the pipe population and on the population's "demographics," including the age and type of pipes installed, and the cost of leak repair and replacement cost per foot. The cost of maintaining an aging individual pipe can be thought of as a risk-cost, that is, it is calculated as the probabilistically expected number of leaks times the likely cost of repair, and the risk cost increases as the pipe ages. Cumulated over all the pipes in the system, this individual pipe risk cost becomes a steady, predictable annual system maintenance cost that rises as the general infrastructure ages.

Inputs to the model

Pipe characteristics

The Waverider model breaks the pipe population into nine categories based on material, size, and date of installation. The categories are intended to group classes of pipes with similar aging and cost characteristics. For example, small diameter (<12") cast iron pipe installed before 1920 is expected to have a longer economic life than cast iron pipe installed between 1920 and 1940; both of these groups are expected to last longer than cast iron pipe installed after 1940. In this case, the differences in economic life are due to changes in materials and construction standards over time, which causes the rate of deterioration of the pipes to vary.

Table 1 below shows the categories of pipes, their designations in Waverider, and the approximate number of miles installed.

Table 1: Pipe Category Descriptions

Pipe Category	Pipe Type	Total Miles of Pipe
WM1	Ductile Iron	203
WM2	Cast Iron <12" and installed before 1920	295
WM3	Cast Iron <12" and installed between 1920 and 1940	321
WM4	Cast Iron <12" and installed after 1940	635
WM5	Cast Iron >12"	119
WM6	Steel (large diameter)	150
WM7	Concrete (large diameter)	62
WM8	Galvanized Steel and Iron (small diameter)	50
WM9	Other	5

For each pipe type, Waverider includes input parameters as shown in Table 2 below. These parameters define the economic life of the pipes, and the rate at which failures are expected to increase as the pipe approaches the end of its economic life. These inputs will be explained in more detail in subsequent sections.

One key parameter for each pipe type is the expected economic life. This is the age at which it is expected to be more economical to replace the pipe than to leave it in place and continue to repair failures. The economic life, then, is the direct basis for the replacement program.

Table 2: Input Variables for Waverider Model

	Pipe Category			
	WM1	WM2	WM3	WM4
INPUT VARIABLES	DI	CI <12" and<1920	CI <12" >1920 and<1940	CI <12" and>1940
Economic Life (years)	150	190	170	140
Standard Deviation of Economic Life (years)	30	30	30	30
Average Number of Failures per Year/mile	0.01	0.04	0.04	0.06
Shape Parameter b	5	5	5	5
Cost per Failure ($)	$3,500	$3,500	$3,500	$3,500
Replacement Cost per Foot	$330	$330	$330	$330
Annual Growth in Watermains				
Break Years	40	40	40	40
Percent economic replacement	100%	100%	100%	100%
Discount Rate	5.00%			
Current actual failures/100mile /yr	0.7	3.7	4.3	6.5
Predicted current failures/100mile /yr	0.1	4.1	4.7	5.9
Current actual replacement length/yr ft	0	300	300	800
Predicted current replacement length/yr ft	2	172	216	554

For each pipe category, Waverider includes an estimate of the replacement cost per foot, as well as an estimated cost to repair an unexpected leak. SPU uses historical construction costs to estimate replacement costs; Table 3 shows sample estimates recently used (2004) by pipe category.

Table 3: Replacement and Repair Costs

Pipe Category	Replacement Cost (per foot)	Repair Cost (per event)
WM1	$ 330	$ 3500
WM2	$ 330	$ 3500
WM3	$ 330	$ 3500
WM4	$ 330	$ 3500
WM5	$ 400	$ 8000
WM6	$ 605	$ 10000
WM7	$574	$ 10000
WM8	$ 330	$ 3500
WM9	$ 330	$ 3500

Description of pipe categories

Waverider includes a database of the feet of each pipe type currently installed, based on their estimated replacement cost at the current per-foot rates. This database ranges from 1890 to the current year. For example, cast iron pipe that is less than 12” in diameter and installed after 1940, pipe category WM4, has the distribution of replacement cost which reflects the actual years of installation for this category of pipe.

Computation

Replacement cost

The first step in the long term projections is to determine the cost stream for pipe replacement. Waverider projects the replacement cost for each pipe category by normally distributing the installation costs, based on the age distribution of each pipe category, around the economic life.

For example, in 1958, approximately 206,000 feet of category WM4 pipe was installed, with a present-day replacement value of $68 million. The projected replacement cost is determined by assuming that on average this pipe will be replaced when it reaches it economic life of 125 years. In order to reflect the uncertainty of this projection, however, the installation cost is normally distributed with the mean value in the year the economic life and the standard deviation as defined in the input database – 35 years in this case. Therefore, in our example, the peak of the cost distribution will occur in 2083, which is when the population reaches 125 years of age, as shown in Figure 2.

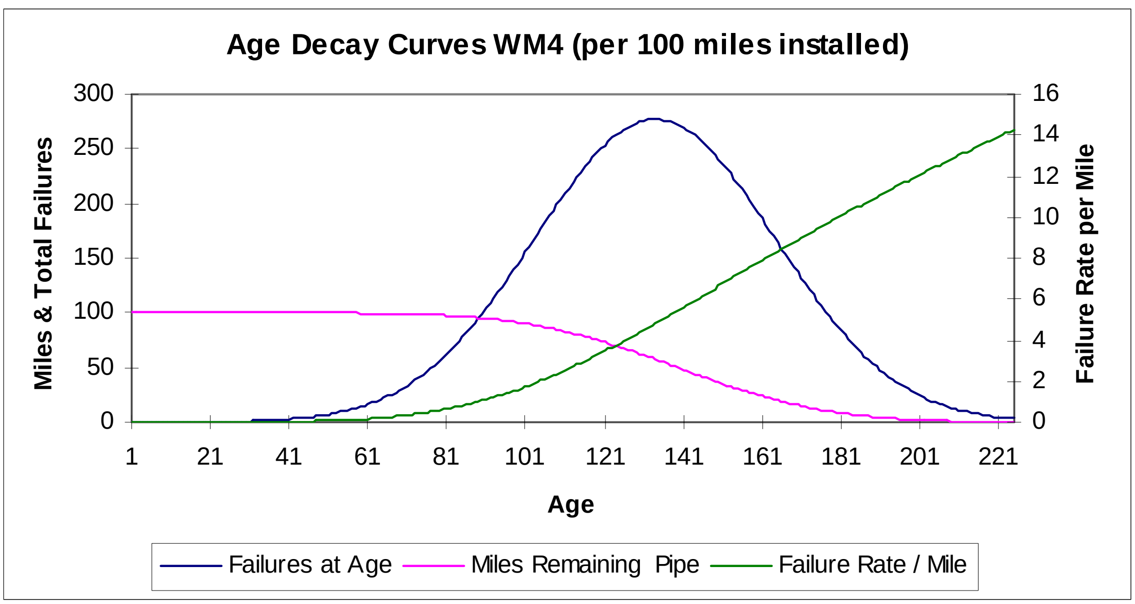


Figure 1. Age Decay for WM4 Pipe Category

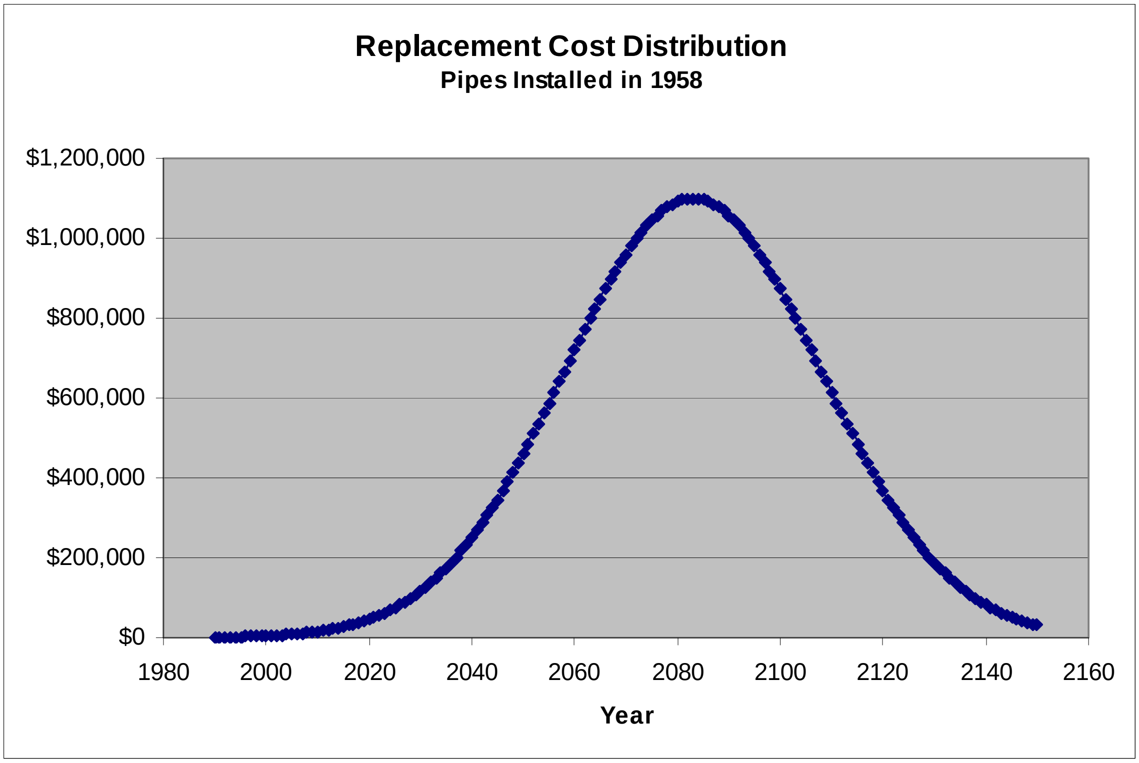


Figure 1: Replacement Cost for Pipe Category WM4 installed in 1958

This calculation is carried out for each installed date for the entire WM4 pipe population, which results in a cumulative replacement cost for the WM4 category, as shown in Figure 3. This curve is simply the sum of the curves for each age of pipe, like the one shown above for the pipes installed in 1958. There is another, similar curve generated for pipes installed in 1959, 1960, and so on. These are added together to create the curve in Figure 4, which includes all pipe categories.

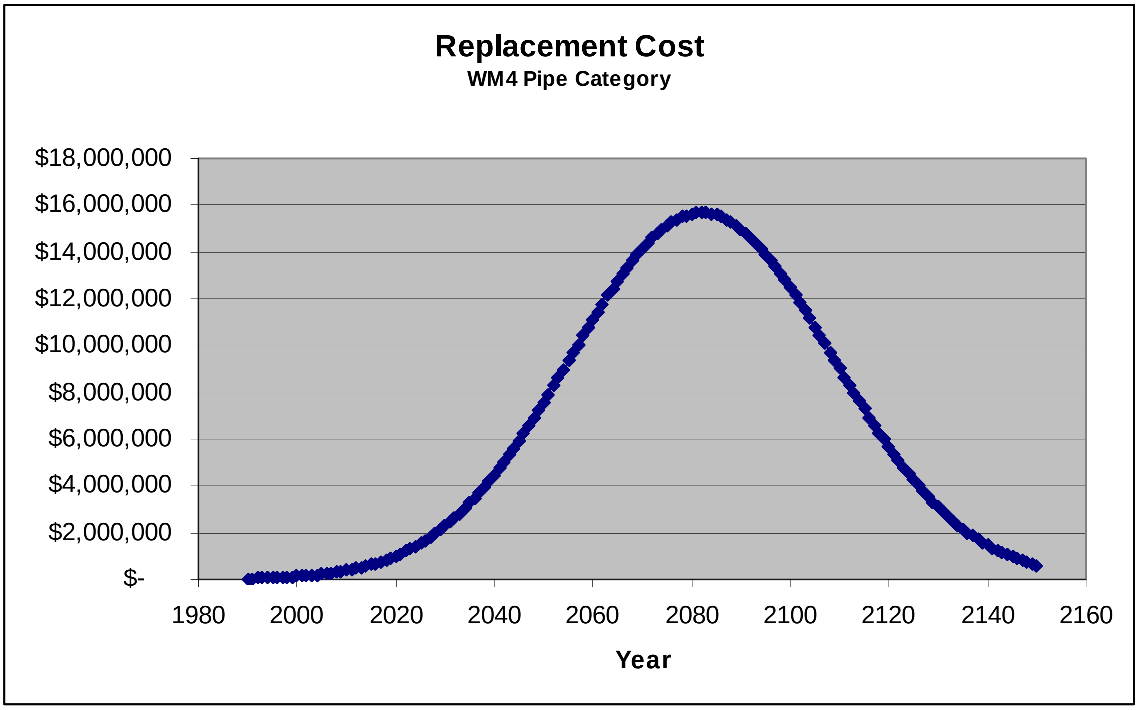


Figure 2: Replacement Cost for Entire WM4 Population

Figure 4 below shows a composite replacement projection for all nine pipe categories in Waverider.

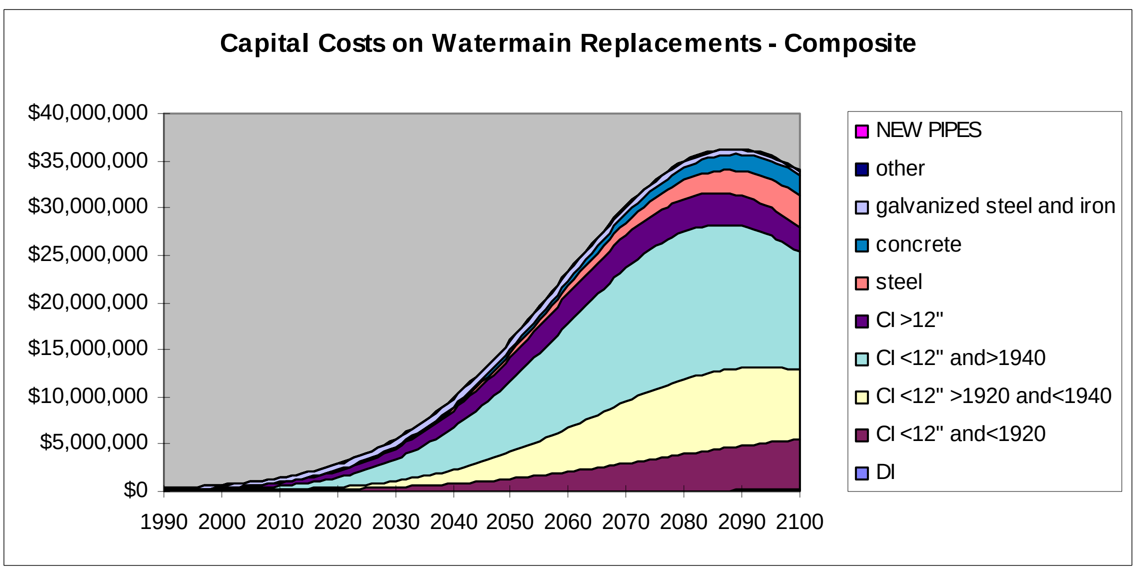


Figure 3: Replacement Cost for All Categories of Pipes

Reactive cost

Prior to a pipe's replacement, as determined by the predicted replacement timing, reactive costs will be incurred. Reactive cost, or risk cost, is the cost incurred for pipe repair due to failures. Reactive cost increases over time as the pipe ages until the expected cost of repair becomes more than the cost of replacement. At that point, the risk cost becomes so great that it is more economical to replace the pipe.

In general, pipe replacement is economically justified when the cost of replacement is lower than the projected cost of future failures. Specifically, when the marginal expected repair cost (annual probability of failure times repair cost) for a pipe in a given year is higher than the annualized cost of the new pipe, the pipe should be replaced. This is shown in Figure 5 below.

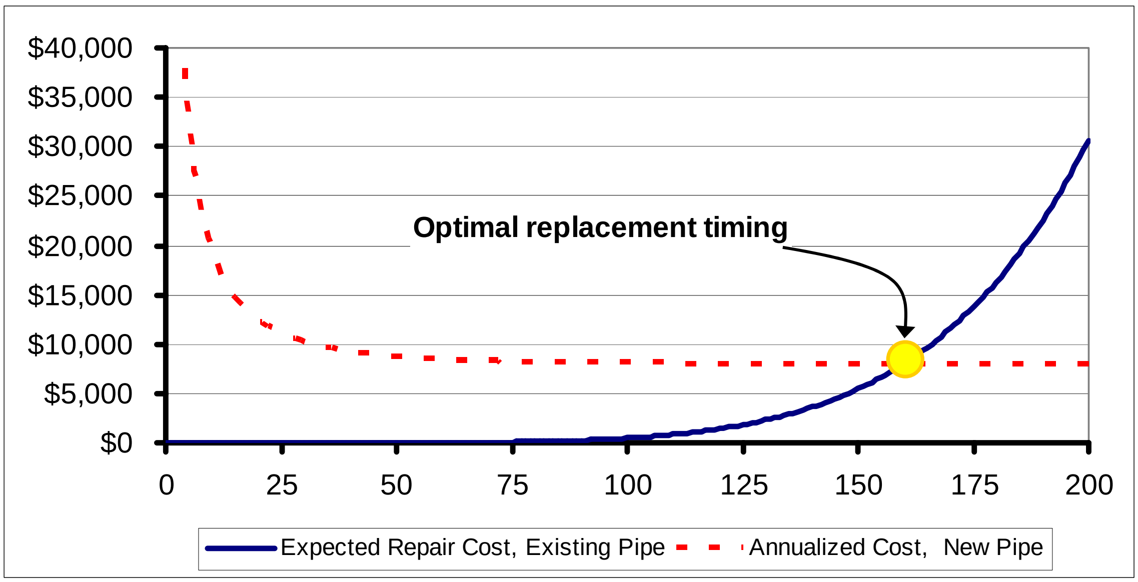


Figure 4: Optimization of Replacement Timing

Waverider recognizes this economic condition for pipe replacement, therefore the reactive costs are calibrated so that pipe replacement comes at the point where ongoing reactive costs just surpass replacement cost. Waverider calculates the annualized cost of the new pipe, based on its economic life, capital cost, and the discount rate, and adjusts the reactive cost projection for the existing pipe so that the reactive cost at the end of economic life is equal to the annualized cost of the replacement pipe. The number of failures needed to justify replacement of a pipe is referred to as the "break even rate."

As shown in Figure 5 above, the projected number of repairs, which is of course proportional to the cost of repairs, starts low and rises until it reaches the break even rate, at the end of economic life of the pipe. The curve defining the rate of this rise is based on two input parameters shown in Table 2: Break Years, which defines the number of years before end-of-economic life when the failures are expected to begin, and the shape parameter, which defines the concavity of the curve.

These parameters are used in a modified Weibull curve, using the formula shown below. This formula defines a base failure probability as a function of age. It is multiplied by the break-even rate to give the projected number of failures; and this result is multiplied by the repair cost per failure to give the projected repair cost. These are all expressed on a per-mile basis.

Projected Failures per Mile in Year **t** = (Break-even Rate) x $\left(\frac{t-Y+\gamma}{\gamma}\right)^{(\beta-1)}$, = 0 when t > Y, or Y – t > γ

Where *Y = Replacement Year*
t = Current Year
γ *= Break Years*
β *=Shape Factor*

How these terms are used to calculate the projected number of leaks, which leads to reactive cost, is shown in Figure 6 below. This figure demonstrates how the number of leaks is calibrated to reach the break-even rate, 25 in this case, in the replacement year of the pipe.

The break-even rate for WM4 pipe is 25 failures per mile, meaning that once the expected number of failures reaches 25 per mile, it is cheaper to replace the pipe than to continue to repair it. Figure 6 shows the projected number of failures leading up to the replacement in these pipes in year 2060. This shows the failures starting 40 years before replacement, 40 being the “break years” defined for this category of pipe.

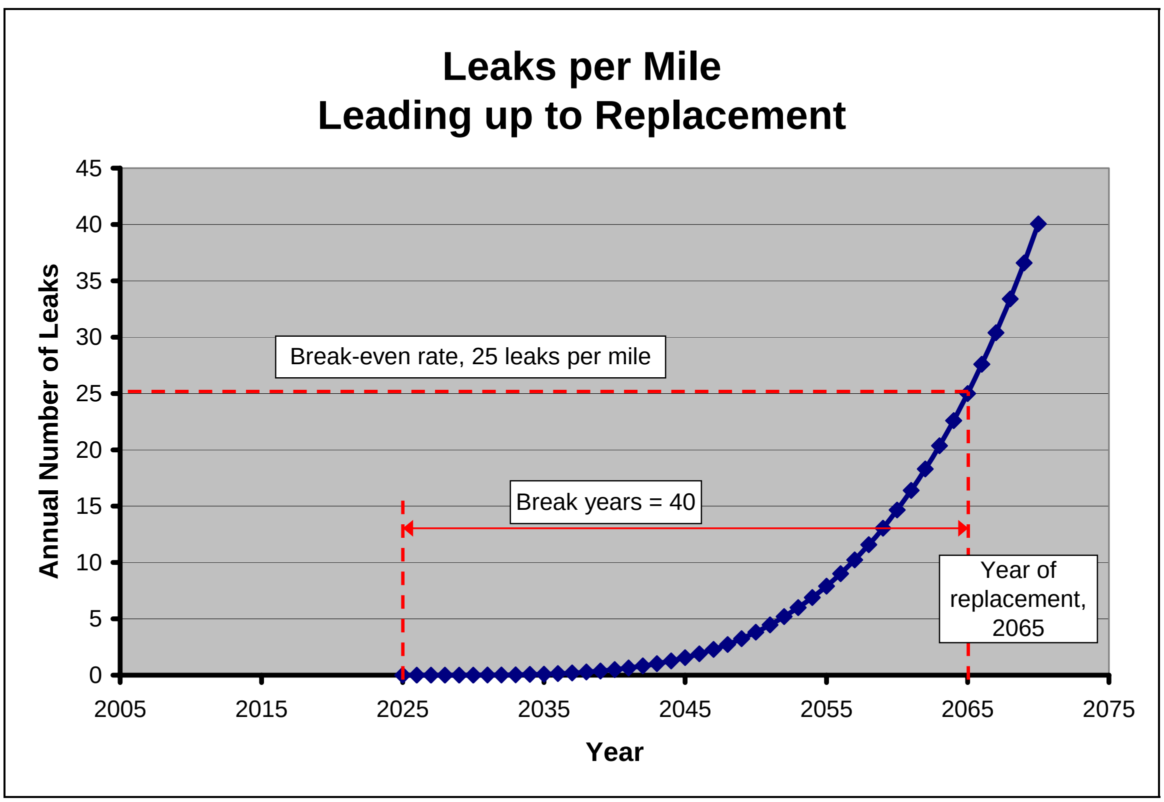


Figure 5: Leaks per Mile Leading up to Replacement

The total number of failures projected in a given year is the composite number of failures from each subset of the population. For example, the replacement program for WM4 pipes includes some number in each year looking forward. The quantity in each year depends on the current age distribution, the economic life of the pipe category, and the standard deviation assumed for the normal distribution. Figure 7 shows the WM4 replacement program from Figure 6 above, indicating a particular year's installation projection: $11 million in 2060 which is approximately 6 miles of pipe.

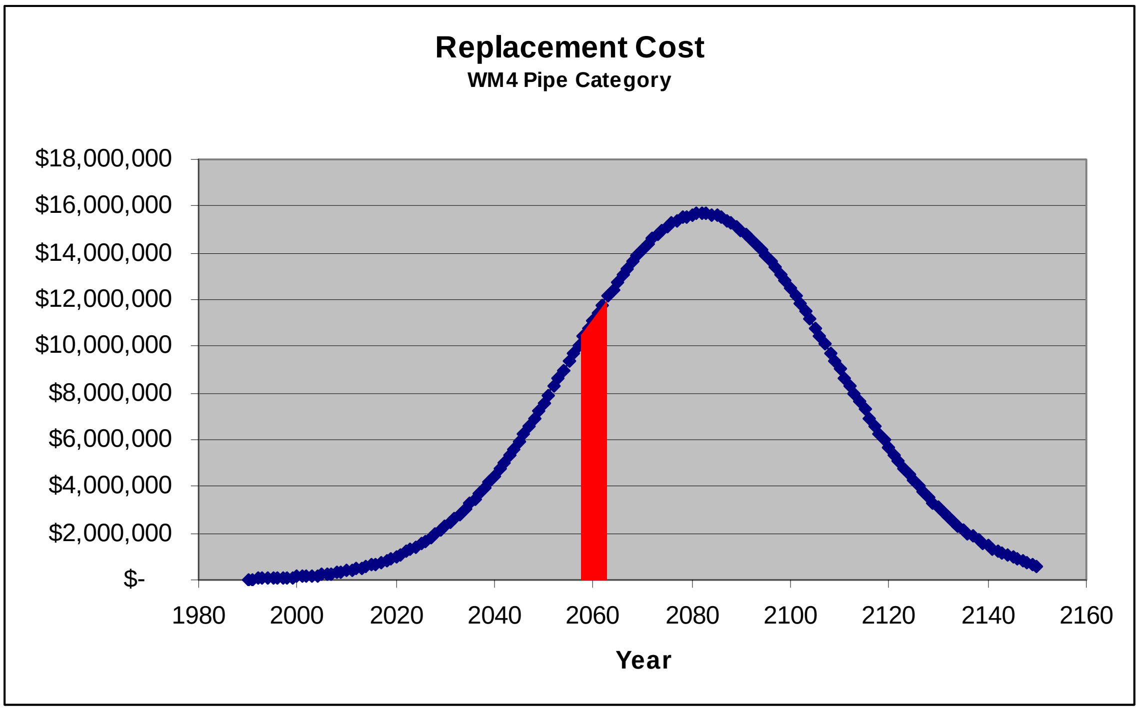


Figure 6: Replacement Cost for Entire WM4 Population; Indicating 2060 Replacement Cost

The number of leaks from this segment of the population will follow the curve in Figure 6, with economic replacement in 2060 and the failures beginning in 2020. The number of leaks from this segment will be six times that shown, however, since there are six miles in the segment. In this way, we can calculate the number of leaks and the reactive cost year-by-year up to the time of replacement, at which time the number of leaks drops to zero.

This calculation is repeated for each year's replacement program to produce a series of projected leaks from each segment (i.e., year 2010 program, year 2011 program, etc.). The cumulative reactive cost for the WM4 population is shown in Figure 8. This is simply the sum of the reactive cost projections for each segment of the WM4 population.

As discussed above, the projection of failures is multiplied by the cost per failure to give a projection of the reactive cost for this particular subset of pipes (i.e., WM4, to be replaced in 2060). These are added together to give the cumulative reactive cost projection for the entire category, as shown in Figure 8.

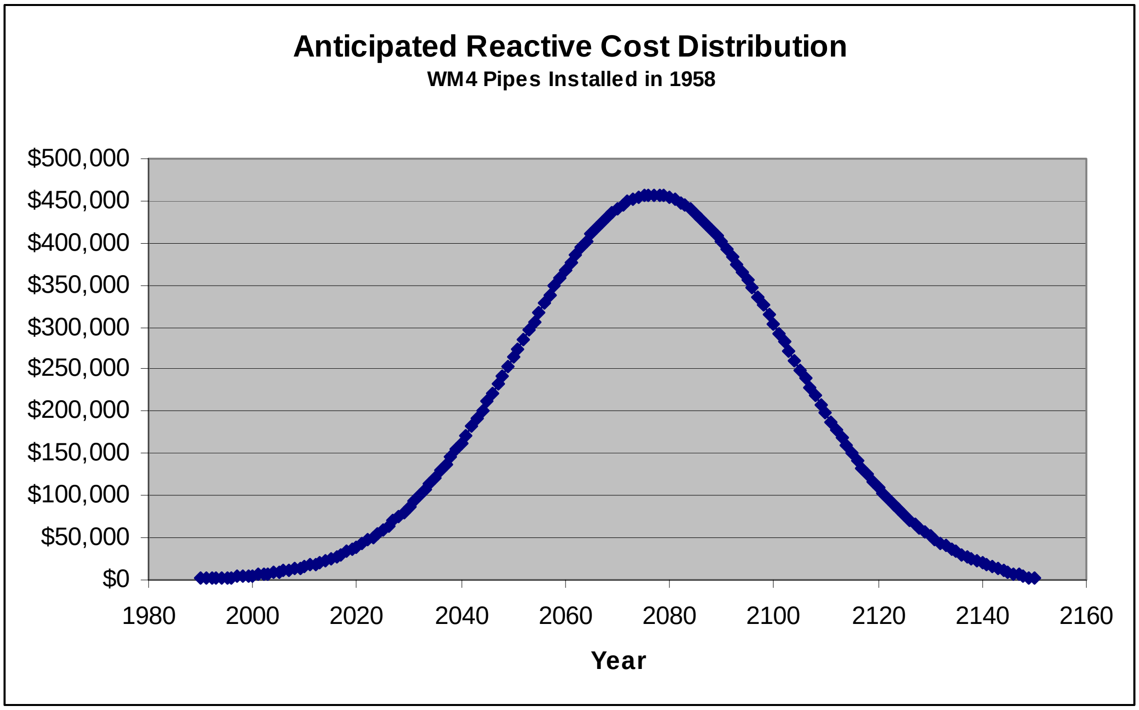


Figure 7: Reactive Cost Distribution for WM4 Pipes Installed in 1958

Figure 9 shows the reactive costs for the entire pipe population, including WM4 and all the other pipe categories. This is simply the sum of the reactive cost curves for each category. A similar, proportional summary is also created to project the total number of leaks over time.

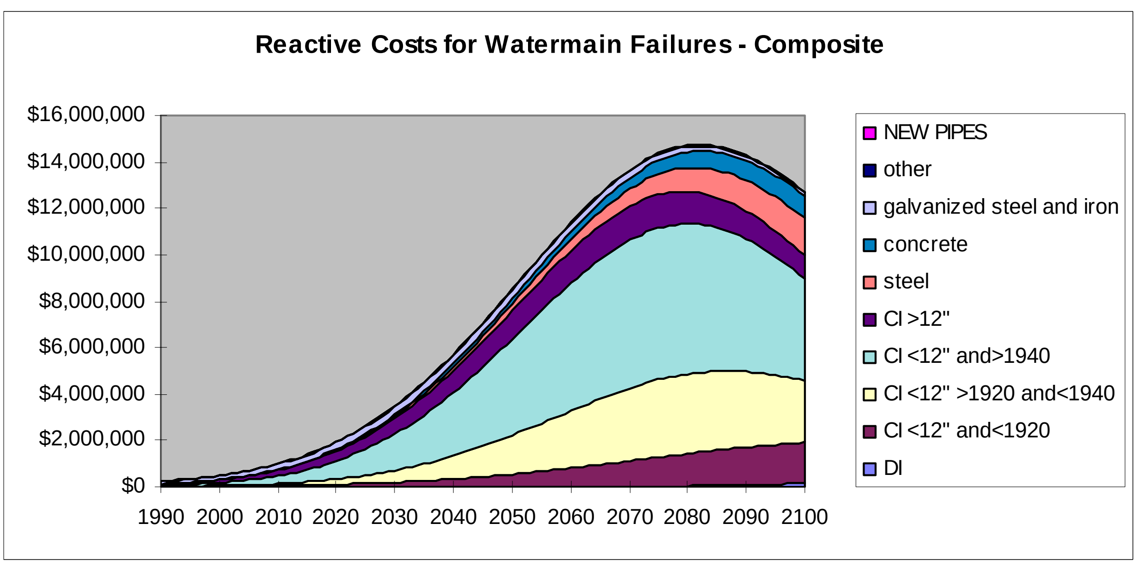


Figure 8: Reactive Cost for Full Population of Pipes

Calibration

Waverider can be calibrated so that the current number of leaks calculated by the model is the same as the actual current number of leaks in SPU's system, and so that the predicted replacement cost matches the actual cost. This helps to ensure that the model's projections of replacement cost and leaks are tied to SPU's actual experience. In the future, as SPU collects data to support its failure probability curves, it will be possible to calibrate the model to match the rate of leaks not only one point in time, but multiple points.

The model is calibrated by adjusting the economic life, break years, and skew, which define the rate at which failures appear as the pipes age. The standard deviation of the normal distribution is also adjusted, which affects how many pipes reach their end-of-life ahead of time. These parameters are adjusted to match the actual failure data and replacement rate for each pipe category.

There are four adjustable parameters, which mean that there are probably many combinations of them that will match the current rate of leaks and spending. In practice, SPU adjusts mainly the economic life; the other terms are generally left at their default values. Once this is done, the inputs and projected performance of the system are reviewed by SPU's operations staff to verify that the results seem reasonable from a practical perspective.

Glossary

Annualized Cost	Constant annual payment required to provide the same present value as another, variable cost stream.
Break Even Rate	The number of failures in a single year that indicate a pipe has reached the end of its economic life.
Break Years	The number of years over which failures are expected to increase from zero to the break-even rate.
Cost Stream	Series of yearly expenditures, may include fixed and variable costs.
Economic Life	Duration an asset can be economically owned and operated to minimize life cycle cost.
Life Cycle Cost	Total cost of ownership of an asset over its life; usually expressed as a present value or annualized cost.
Marginal Cost	Incremental or variable costs incurred in a given year.
Reactive Cost	Costs incurred in response to leaks or other failures.
Risk Cost	Expected cost due to failures; product of annual probability of failure and expected consequences.
Weibull	A statistical distribution, common in risk and reliability analyses.

APPENDIX C
Pipeline Replacement Model Document

BROWN AND CALDWELL

Technical Memorandum

Seattle Public Utilities
Water Plan Update (28901)
Task 7 – Distribution System Renewal Strategy

Date: December 14, 2005

To: Bill Wells, SPU
Jon Shimada, SPU
Tim Skeel, SPU

From: Darin Johnson, BC

Copy to: Andrew Lee, BC
Corinne DeLeon, BC
Scott Anschell, BC
File

RE: Water Main Replacement Model

SPU Renewal Strategy – Pipe Replacement Model

Description of Methodology

The objective of the pipeline replacement model is to provide an analytical framework for developing a near-term pipe replacement program based on minimizing life cycle costs. The model provides an economic justification for replacing aging pipes based on the benefit of avoided risk cost. Pipes with a series of recent failures are analyzed to determine whether they ought to be replaced in the near-term. The model compares the cost of a new pipe to the increasing expected cost of repairs for the existing pipe, to determine the correct strategy of replacement or continued repair.

The cost of repairs is expressed probabilistically, using the expected consequences of a failure multiplied by the probability that the failure will occur in a given year. This product is called the marginal risk cost. In the pipe replacement model, the probability of failure is based on the historical rate of failure for the pipe in question over the last few years and projected into the future using a Weibull curve calibrated to the historical failure rate. The model uses this to quantify the cost of continued operation of a pipe, and to compare it with the cost of replacement, which reduces risk cost by reducing the probability of failure.

The pipe replacement model considers both the fixed cost of replacement for a pipe and the incremental or marginal cost of repairs. For each pipe, SPU has estimated the replacement cost, calculated on a cost per foot of pipe basis. This estimate includes the direct, capital costs as well as indirect costs. Construction costs include the following.

- Capital cost

- Interruption of service
- Interruption of traffic
- Diminished water quality during construction.
- Claims costs

SPU has developed standardized scales and methods for expressing indirect costs, such as interruption of service, traffic effects, and diminished water quality, in dollars, so these costs can be considered on equal footing with the capital costs. These methods consider the number of customers affected, the duration of the effect, and its significance.

The other component of life cycle costs are the variable costs, which are the repair costs incurred due to failure. The variable costs include:

- Repair cost per leak
- Interruption of service
- Interruption of traffic
- Water loss from a leaking pipe
- Cost due to fire flow effects
- Diminished water quality during construction.

The repair cost per leak is defined using SPU's historical costs. Like the fixed costs, the variable costs include indirect impacts, such as service outage and traffic effects, which are quantified in the same way as for repair.

In order to determine whether a pipe should be replaced, the pipe replacement model performs the following calculations.

- The model calculates the annualized cost of a new pipe. This can be thought of as the "annual payment" SPU would have to make to finance this pipe over its entire economic life. It must include not only the initial, fixed cost for installation, but also the projected risk cost throughout the life of the pipe. The annualized cost is based on a discount rate defined by SPU. Implicit in the calculation is the determination of the expected economic life of the new pipe.
- Next, the model calculates the marginal cost for the existing pipe. This is simply the risk cost, based on the recent annual rate of leaks (the calibrated Weibull curve together with the leak rate defines the probability of failure) and the cost to repair a leak.
- Finally, the model compares the annualized cost of a new pipe with the expected marginal cost of the existing pipe. If the annualized cost of the new pipe is smaller than the marginal risk cost of the existing pipe, then it is less expensive to replace the pipe. On the other hand, if the risk cost is smaller,

then it is cheaper to continue to operate the existing pipe and repair it when it leaks.

Application of Methodology

The tables below show the inputs used in the pipe replacement model. Table 1 shows the inputs defining the variable costs. These are related mainly to the existing pipe, defining the pipe itself, the probability of failure (i.e., developing a leak), and the parameters needed to define the consequence cost of a leak. However, these inputs also apply to the new pipe, for calculating its life cycle cost, which must include variable costs.

Table 1: Inputs Defining Variable Costs

Option	*Data Class*	*Input Variables*	*Input Values*
Leak Repair	Pipe	Pipe Length Miles	0.063
Leak Repair	Pipe	Leaks per Mile per Year in Year 1	25.4
Leak Repair	Pipe	Pipe Age	76.0
Leak Repair	Construction	Leak Repair Hours	5
Leak Repair	Construction	Persons per Repair	3
Leak Repair	Construction	Cost per Person per Hour	$ 50
Leak Repair	Construction	Equipment Pieces per Repair	3
Leak Repair	Construction	Cost per Equipment Piece per Hour	$ 75
Leak Repair	Construction	Material Cost	$ 625
Leak Repair	Construction	Total Cost per Leak	$ 2,500
Leak Repair	Service	Hours Service Interruption per Leak	3
Leak Repair	Service	Customers Impacted per Leak	48
Leak Repair	Service	% Leak Repairs w/ Water Shutoff	50%
Leak Repair	Service	Cost per Customer per Hour	$ 5
Leak Repair	Traffic	Hours Traffic Interruption	5
Leak Repair	Traffic	Traffic Flow Cars per Hour	40
Leak Repair	Traffic	Cost per Car	$ 2
Leak Repair	Lost Water	Hours of Water Loss per Leak	168
Leak Repair	Lost Water	Gallons Lost per Hour	25
Leak Repair	Lost Water	Cost per Gallon Lost	$ 0.002
Leak Repair	Damage	Number of Damage Claims per Leak	0.167
Leak Repair	Damage	Settlement Cost per Claim	$ 2,000
Leak Repair	Fire Risk	Customers Impacted Fire Flow	0
Leak Repair	Fire Risk	Property Value per Customer	$ 500,000
Leak Repair	Fire Risk	Probability each Year Fire w/ Inadequate Fire Flow	0.00001
Leak Repair	Fire Risk	Damage % Property Value	100%
Leak Repair	Water Quality	Customers Impacted Low Water Quality	48
Leak Repair	Water Quality	Cost per Customer per Leak Low Water Quality	$ 25

Many of the inputs shown in Table 1 are standardized; they the same for an analysis of any pipe in the system. These include the hourly rate for construction labor, the cost per customer-hour of outage, the cost per car for traffic delays, and others. The intent is to ensure that the calculations are consistent across the entire system, regardless of who does the analysis and from one year to the next.

Table 2 shows a summary of the inputs used to define the fixed costs associated with replacement of the pipe. Again, many of these inputs are standardized and are the same for every pipe segment analyzed. Also, where appropriate, they are the same as those in Table 2; for example, the cost per car delayed.

Table 2: Inputs defining fixed costs (replacement cost)

Replacement	Pipe	New Pipe Economic Life Years		150
Replacement	Construction	Replacement Construction Cost per Foot	$	469
Replacement	Service	Hours Service Interruption During Construction		5
Replacement	Service	Customers Impacted Construction		48
Replacement	Service	Cost per Customer per Hour	$	5
Replacement	Traffic	Hours/Project Traffic Interrupt During Construction		72
Replacement	Traffic	Feet per Project		300
Replacement	Traffic	Traffic Flow Cars per Hour		10
Replacement	Traffic	Cost per Car	$	2
Replacement	Water Quality	Customers Impacted Water Quality Construction		48
Replacement	Water Quality	Cost per Customer Low Water Quality	$	10
Replacement	Benefits	Customers Gain Improved Service Levels		48
Replacement	Benefits	Annual Benefit per Customer Improved Service	$	-

Note: Many of these inputs are variable dependent on the site.

Description of Calculations

Economic Life and Annualized Cost of New Pipe

The first step in determining the costs related to a new pipe is to calculate the economic life and the annualized costs for a new pipe. This is based on the same methodology as described above: identifying the year in which the repair cost is expected to supersede the annualized cost.

This requires first a projection of the expected marginal repair costs. Since the new pipe requires a long-term projection of risk cost rather than a one-year comparison, recent historical failure rates are not appropriate for estimating failure probability. Instead, the probability of failure is projected using a form of the Weibull curve:

$$\lambda(t) = \frac{\beta}{\theta}\left(\frac{t - t_0}{\theta}\right)^{\beta - 1}$$

The shape parameter, β, is referred to as the “Skew” in the replacement model. The characteristic life, or scale parameter, θ, is simply referred to as “Life” in the replacement model. The location parameter, t_0, refers to the “First Fail” in the replacement model. Each of these terms is defined by SPU in the pipe replacement model. Where possible, they are based on long-term failure data from SPU and other utilities. The typical Weibull curve in the replacement model resembles the curve in Figure 1.

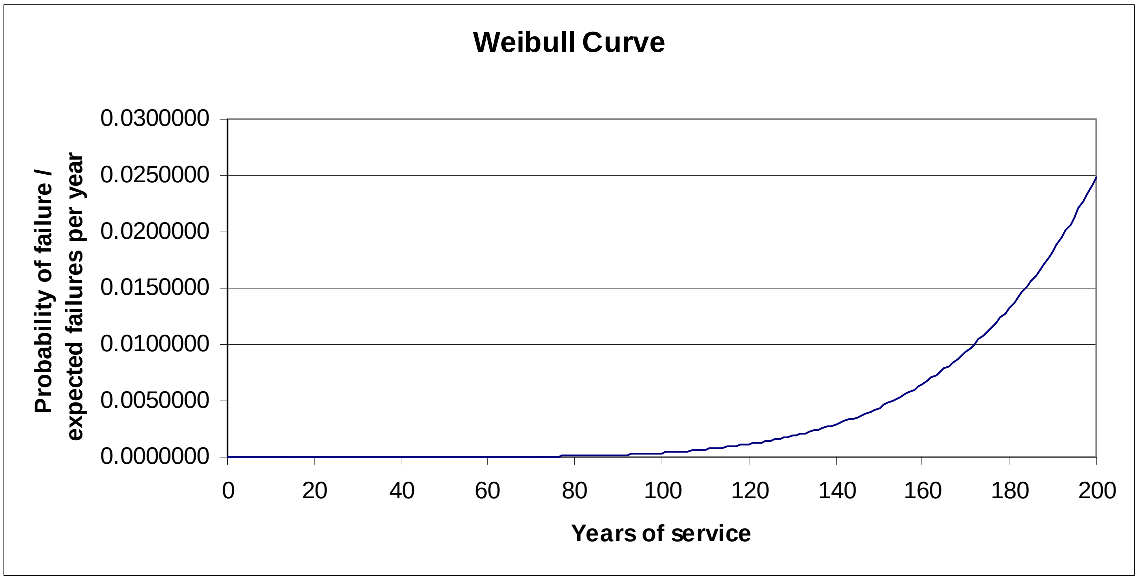


Figure 1: Weibull Curve Defining Annual Probability of Failure

The projected number of repairs is the product of the probability of failure and the length of pipe in miles. The marginal repair cost is then the product of the projected number of repairs and the cost per repair. Repair costs are annualized by calculating the "annual payment" necessary to cover the projected repair costs for a given lifespan. For example, as the expected lifespan of the pipe increases, the annualized cost of the repairs also increases since the risk cost increases with time, requiring a higher "payment" to cover it.

The other component of total cost is the initial, fixed cost of installation. This cost is annualized by determining the fixed annual payment at SPU's discount rate, that would return the same present value as the initial cost over the number of years of the expected economic life. For sake of illustration, think of dividing the fixed cost by the number of years of the expected economic life. For example, if the expected life is one year, then the annualized replacement cost is the full replacement cost, since the pipe is replaced each year. If the expected life is two years, the annualized cost is only half the replacement cost, since the pipe is replaced only every other year. Of course, if the expected life is 150 years, then the annualized cost is less than 1% of the replacement cost. This explanation is somewhat simplistic, since it ignores the effect of discounting, which further reduces the annualized cost as the expected life increases.

The sum of the annualized repair cost and the annualized replacement cost gives the annualized life cycle cost of ownership as a function of the life of the pipe. As the life increases, the annualized capital cost decreases (because replacements are spread out further and delayed), but the annualized repair cost increases (because the longer the pipe is in service, the more likely it is to experience a high rate of failures). In general, there is an optimal point, where the total cost is at a minimum, as shown in Figure 2 below.

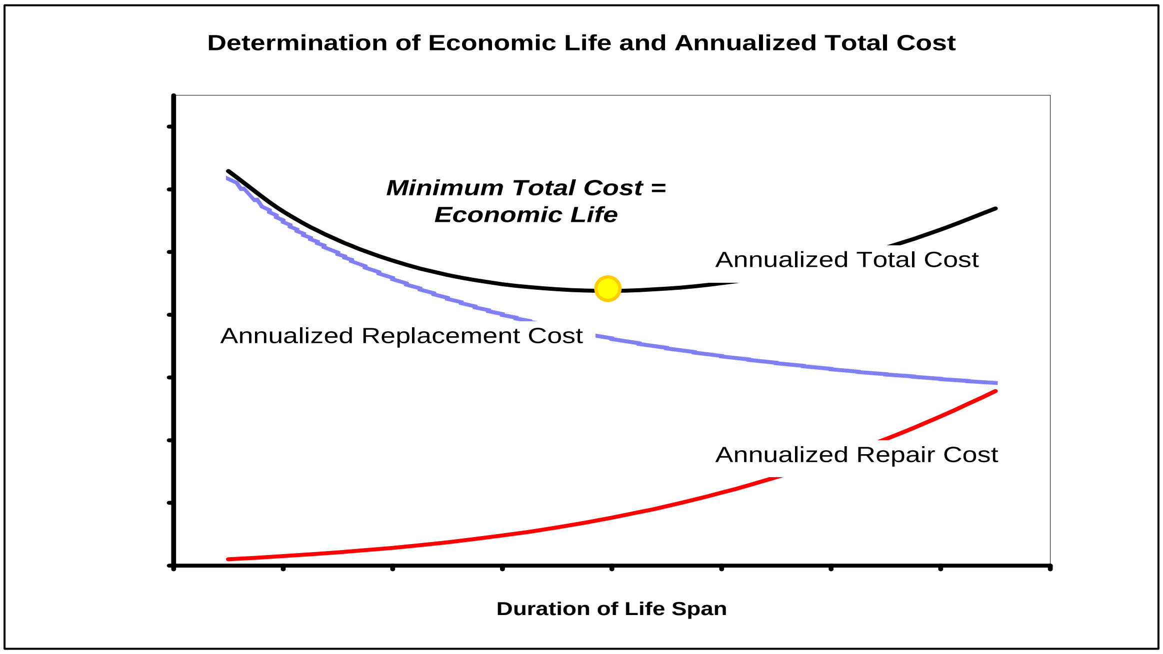


Figure 2: Determination of Economic Life by Minimizing Life Cycle Cost

Expected Marginal Repair Cost of Existing Pipe

The calculations to determine the expected marginal costs for the existing pipe are similar to those used for a new pipe. The probability of failure is again derived from the Weibull curve, however this time the expected number of leaks is calibrated to match the actual number using the Repair Factor, which is a constant multiple applied to the risk cost to ensure that the number of leaks projected in year 1 is equal to the Leaks per Mile in Year 1 shown in Table 1.

Similar to the new pipe, the projected number of repairs for the existing pipe is the product of the probability of failure and the Repair Factor (which is explicitly calculated using the length of pipe in miles). The Marginal Repair Cost is then the product of the projected number of repairs and the cost per repair.

Comparing New and Existing Pipe Costs

Having calculated the expected repair costs with the existing pipe and the annualized cost for a new one, the pipe replacement model then compares the two to determine whether replacement of the pipe is economically justified. Replacing the pipe is economically justified when the expected cost of repair exceeds the annualized for the new pipe. In the terms of the replacement model:

- If the projected marginal repair cost of the existing pipe **exceeds** the annualized cost of a replacement pipe, it is economically justified to replace the existing pipe.
- If the projected Marginal Repair Cost is **less** than the annualized cost of a replacement pipe, it is not economically justified to replace the existing pipe.

- ♦ If replacement is not justified, the pipe replacement model is able to predict the year in which it will be justified, by extrapolating the rate of leaks in the existing pipe based in the Weibull curve, calibrated to match the current rate of leaks.

Outputs of the Model

The primary output of the pipe replacement model is a basis for deciding whether to replace pipes that show significant rate of recent leaks. For those pipes that have reached end-of-life and should be replaced, the model calculates the net present value of the replacement program, based on the difference in life cycle costs between the optimal, replacement program and leaving the pipe in place. This is calculated for a range of discount rates to demonstrate the sensitivity of the result.

Tables 3 and 4 below show the first five years of costs calculated by the model in a sample analysis. Table 3 shows the calculations related to the existing pipe used in producing the Marginal Repair Cost values, based on the projected cost due to leaks. The total leak cost is comprises the repair cost, service interruption cost, traffic interruption cost, water loss cost, and damage claim cost. This is calculated for each year out to 20 years. The "Present Value Leak Cost and Deficiencies @ 5%" is the net present value of the 20 years of annual leak costs.

Table 4 shows the calculation of costs associated with the new pipe. Like the existing pipe calculations, this includes costs related to all aspects of installation. The total cost of replacement includes the construction cost, service interruption cost, traffic interruption cost, and diminished water quality cost. The "Present Value of 20 Years @ Life cycle Cost" is the net present value of 20 years of the annualized cost of pipe replacement.

Both of these tables also indicate how costs and benefits are distributed between SPU and the community

Table 3: Existing Pipe Cost Calculations (five years shown)

	Year1	Year2	Year3	Year4	Year5
Leak Rate Escalator	0	1	2	3	4
Pipe Length Miles	0.063	0.063	0.063	0.063	0.063
Leaks per Mile per Year	25.400	27.116	28.923	30.825	32.826
Total Leaks	1.6	1.7	1.8	1.9	2.1
Leak Repair Hours	5.000	5	5	5	5
Persons per Repair	3.000	3	3	3	3
Cost per Person per Hour	50.000	$ 50	$ 50	$ 50	$ 50
Equipment Pieces per Repair	3.000	3	3	3	3
Cost per Equipment Piece per Hour	75.000	$ 75	$ 75	$ 75	$ 75
Material Cost	625.000	$ 625	$ 625	$ 625	$ 625
Total Leak Repair Cost	$ 4,005	$ 4,275	$ 4,560	$ 4,860	$ 5,176
Hours Service Interruption per Leak	3.000	3	3	3	3
Customers Impacted per Leak	48.000	48	48	48	48
Cost per Customer per Hour	5.000	$ 5	$ 5	$ 5	$ 5
% Leak Repairs w/ Water Shutoff	50%	50%	50%	50%	50%
Total Cost Service Interruption	$ 577	$ 616	$ 657	$ 700	$ 745
Hours Traffic Interruption	5.000	5	5	5	5
Traffic Flow Cars per Hour	40.000	40	40	40	40
Cost per Car	2.000	$ 2	$ 2	$ 2	$ 2
Total Traffic Interruption Cost	$ 641	$ 684	$ 730	$ 778	$ 828
Hours of Water Loss per Leak	168.000	168	168	168	168
Gallons Lost per Hour	25.000	25	25	25	25
Cost per Gallon Lost	0.002	$ 0.002	$ 0.002	$ 0.002	$ 0.002
Total Cost Water Loss	$ 13	$ 14	$ 15	$ 16	$ 17
Number of Damage Claims per Leak	0.167	0.167	0.167	0.167	0.167
Settlement Cost per Claim	2000.000	$ 2,000	$ 2,000	$ 2,000	$ 2,000
Total Damage Claim Cost	$ 534	$ 570	$ 608	$ 648	$ 690
Total Leaks Cost	$ 5,770	$ 6,159	$ 6,570	$ 7,002	$ 7,457
Customers Impacted Fire Flow	0.000	0	0	0	0
Property Value per Customer	500000.000	$ 500,000	$ 500,000	$ 500,000	$ 500,000
Probability each Year Fire w/ Inadequate Fire Flow	0.000	0.00001	0.00001	0.00001	0.00001
Damage % Property Value	1.000	100%	100%	100%	100%
Total Cost Fire Risk	$ -	$ -	$ -	$ -	$ -
Customers Impacted Low Water Quality	48.000	48	48	48	48
Cost per Customer per Leak Low Water Quality	25.000	$ 25	$ 25	$ 25	$ 25
Total Cost Low Water Quality	$ 1,922	$ 2,052	$ 2,189	$ 2,333	$ 2,484
Total Community Cost Leaks and Deficiencies	$ 7,692	$ 8,212	$ 8,759	$ 9,335	$ 9,941
	Total	SPU	Community		
Present Value Cost Leaks and Deficiencies @ 3%	$203,772	$106,092	$97,679		
Present Value Cost Leaks and Deficiencies @ 5%	$164,478	$85,634	$78,844		
Present Value Cost Leaks and Deficiencies @ 7%	$134,882	$70,225	$64,656		

Table 4: New Pipe Cost Calculations (five years shown)

New Pipe Economic Life Years		150		
Replacement Construction Cost per Foot		469.000		
Total Construction Cost	$	156,177		
Hours Service Interruption During Construction		5.000		
Customers Impacted Construction		48.000		
Cost per Customer per Hour		5.000		
Total Cost Service Interruption During Construction	$	1,200		
Hours/Project Traffic Interruption During Construction		72.000		
Feet per Project		300.000		
Traffic Flow Cars per Hour		10.000		
Cost per Car		2.000		
Total Traffic Interruption Cost During Construction	$	1,598		
Customers Impacted Water Quality Construction		48.000		
Cost per Customer Low Water Quality		10.000		
Total Cost Low Water Quality from Construction	$	480		
			Community	
Total Community Cost of Replacement Construction	$	159,455	$	3,278
Undepreciated Value after 20 Years	$	135,353		
Present Value of 20 Years @ Life-cycle cost	$	73,239		
	$	99,604		
	$	118,285		
Present Value of 20 Years of Improved Service Benefits		$0.00		
		$0.00		
		$0.00		

Glossary

Annualized Cost	Constant annual payment required to provide the same present value as another, variable cost stream.
Consequence Cost	Cost incurred from a failure event.
Fixed Cost	An up-front cost of ownership that does not change over time.
Life Cycle Cost	Total cost of ownership of an asset over its life; usually expressed as a present value or annualized cost.
Marginal Cost	Incremental or variable costs incurred in a given year.
Repair Factor	Calibrates the theoretical failure rate using the current failure rate; ratio of actual number of failures to the number predicted based on the age of the pipe and its Weibull curve.
Risk Cost	Expected cost due to failures; product of annual probability of failure and expected consequences.
Variable Cost	Costs that are incurred in different amounts year-by-year.
Weibull	A statistical distribution, common in risk and reliability analyses.

APPENDIX D
Leakage Projection Memo

BROWN AND CALDWELL

Technical Memorandum

Seattle Public Utilities
2007 Water System Plan Update (28901)

Date: 12/15/05

To: Bill Wells (SPU)
Jon Shimada (SPU)
Tim Skeel (SPU)

From: Andrew Lee (Brown and Caldwell)
Corinne De Leon (Brown and Caldwell)

Copy to: File

RE: Water System Leakage and Outage Projections

Introduction

Water loss (i.e. "leakage") from water distribution and transmission systems is a significant concern for many utilities nationwide. As water systems across the United States continue to age and deteriorate, water leakage rates are expected to increase. Many states, including Washington State, have existing or proposed "leakage standards" to limit the amount of water loss from leakage. Seattle Public Utilities (SPU) is currently evaluating the impacts of their water main replacement and rehabilitation program on future leakage rates from their transmission and distribution system. This technical memorandum presents three different scenarios on how leakage rates may increase within SPU's system until the year 2100 based on SPU's current water main replacement and rehabilitation. The memorandum covers the following topics:

- Future regulations concerning leakage
- Leakage categories and sources
- "Top-down" estimate of leakage
- Existing leakage data
- IWA method for determining the existing leakage rates
- Three scenarios for projecting leakage rates into the future.

Future Regulations Concerning Leakage

SPU's water system will soon be required to meet a Washington State Department of Health (DOH) standard to minimize loss of water from leakage within its distribution system. The DOH draft rule, found in Chapter 246-290 of the Washington Administrative Code will require water systems with greater than 10,000 connections to maintain water system leakage to less than 10 percent unless achieving that limitation is not technically feasible.

Leakage Categories and Sources

According to the International Water Association (IWA), leaks in municipal water systems can be categorized as follows:

1. Background (i.e., undetectable) leakage
2. Reported leaks and breaks
3. Unreported leaks and breaks

Background leakage is, by definition, leaks that are too small to be detected through modern "sonic" leak detection methods. Background leakage typically occurs through the joints of pipes and can be quantified through nighttime flow analyses. Measures to control background leakage are typically more operational and focus on pressure management in the distribution system.

Reported leaks and breaks are usually the most well-documented water systems leaks. Reported leaks typically have higher flows but last for a shorter duration (3 to 7 days) since they require the highest level of response.

Unreported breaks and leaks can be detected through modern sonic leak detection methods. Without proactive programs to detect these leaks, however, they oftentimes go unnoticed for long periods of time. Unreported leaks have lower flows than reported leaks. However, due to their longer duration, they typically account for a larger total volume of water loss.

The sources of background leakage, reported leaks and breaks, and unreported leaks and breaks include:

1. Broken or leaking water mains (in the public right-of-way (R/W)
2. Broken or leaking service connections

Leaks in any of these infrastructure components can be classified as background, reported, or unreported leaks.

"Top-Down" Estimate of Leakage

In SPU's *2001 Water System Plan Update*, a top-down estimate of pipe leakage was back-calculated from the amount of water that SPU loses annually. The break-down of non-revenue water, which is the difference between water supplied to SPU and metered water is shown in Table 1.

As indicated in Table 1, the quantity of unmeasured losses (leakage from pipelines) was estimated at 5.6 million gallons per day (mgd). This number was calculated by subtracting the values for system operations (3.3 mgd), public uses (0.3 mgd), meter inaccuracies (2.0 mgd), and measured losses (0.8 mgd) from the total non-revenue water (12.0 mgd).

Since 2001, SPU has become increasingly skeptical regarding the numbers used to back-calculate the leakage from pipelines. In 2004, SPU found that reservoir overflow could account for losses as high as 8 mgd. Since the portion of total system losses attributable to reservoir overflows may be higher, the unmeasured pipe leakage may be less than 5.6 mgd.

Table 1. Components of Non-Revenue Water

Classes of Non-Revenue Water	Quantity (mgd)
Total Non-Revenue Water, which consists of:	**12.0**
System Operations	**3.3**
Reservoir overflow	1.2
Reservoir draining/cleaning	2.0
Water main flushing	>0.1
Public Uses	**0.3**
Construction	>0.1
Sewer flushing, fire fighting, street cleaning, etc.	0.2
Meter Inaccuracies	**2.0**
System Losses	**6.4**
Measured losses (reservoir leaks/evaporation)	0.8
Unmeasured losses (pipeline leaks and other)	5.6

Current Programs to Reduce Leakage

SPU is currently implementing several programs to help reduce leakage throughout the system. One example is SPU's service line replacement program to replace plastic, galvanized, ductile/cast iron, and other /unkown material service connections which have high leakage rates with copper connections which have leakage rates that are substantially lower. In addition, SPU has programs to ensure the accuracy of source meters and billing meters. Finally, SPU currently conducts leakage test at reservoirs and is in the process of installing flow measurement devices to measure reservoir overflows. These activities are intended to help reduce the total volume of water loss from reservoirs.

SPU's Existing Leakage Data

SPU's water system consists of over 1,800 miles of transmission and distribution pipes that deliver potable water to over 183,000 customers. Since 1990, SPU has been collecting yearly data on the reported leaks and breaks that occur within its system. SPU does not perform night-flow analyses to determine background leakage, nor does SPU have a proactive leak detection program to detect unreported leaks and breaks.

SPU Data on Reported Leaks and Breaks in Water Mains

SPU's data on reported water main leaks and breaks can be presented several different ways. The reported leaks and breaks data can be broken down by month, by pipe type, by leak/break type, and by size. The data also includes an estimate of the repair cost for each leak based on pipe type. Figure 1 displays average annual numbers for reported leaks. For the last 15 years, SPU has averaged approximately 151 reported leaks/breaks per year.

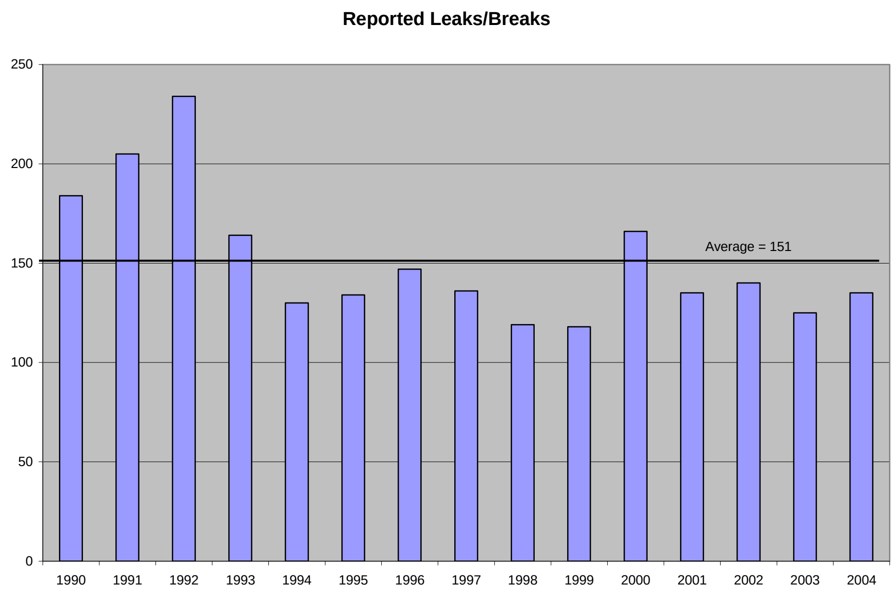


Figure 1. Annual Leaks and Breaks Reported

SPU Data on Reported Leaks and Breaks in Service Connections

SPU also collects data on service connection leaks and breaks for each pipe type as shown in Table 2. Currently, there are over 55,000 service connections composed of plastic, galvanized steel, ductile and cast iron, and other materials not including copper. 30,000 of these service connections are plastic, which have leakage rates that are approximately four times as high as copper service connections. Through a proactive replacement program, SPU plans to replace all of its plastic, galvanized, ductile/cast iron, and other/unknown material service connections with copper by 2015.

Table 2. Reported Service Leak Data

Material	Leaks per year	Number of Services	Leakage Rate
Copper	202	134666	1.5
Plastic	229	32714	7.0
Galvanized	39	11143	3.5
Ductile/Cast Iron	15	4687	3.2
Other/Unknown	30	6977	4.3
Total	**513**	**183214**	**2.8**

Estimate of SPU's Current Leakage Rate Using a Modified IWA Method

The IWA has developed a methodology for calculating unavoidable annual real losses (UARL) for a water system. UARL represents the lowest level of water loss that could exist in a system if it effectively employs the best management practices (BMPs)[1] for leakage management. Table 3 lists the assumed loss rates for the IWA method. These values were calculated based on data obtained from many utilities worldwide.

Table 3. IWA Estimates of Calculating Real Water System Losses per Year

Infrastructure Component	Background (undetectable) Leakage	Reported Leaks and Breaks	Unreported Breaks and Leaks
Mains	8.5 US gal/mi/h	0.20 breaks/mi/year at 50 gpm for 3 days	0.01 breaks/mi/year at 25 gpm for 50 days
Service connections (main to curb stop)	0.33 US gal/service connection/h	2.25 leaks/1000 service connections/year at 7 gpm for 8 days	0.75 leaks/1000 service connections at 7 gpm for 100 days
Service connections (from curb stop to meter	0.13 US gal/service connection/h	1.5 leaks/1000 service connections at 7 gpm for 9 days	0.50 leaks/1000 service connections at 7 US gpm for 101 days

* Committee Report: *Applying Worldwide BMPs in Water Loss Control*, August 2003, Table 4

To calculate SPU's current leakage rate, the IWA method was modified slightly to take into account existing data from SPU on reported leaks and breaks in water mains and service connections. After the modifications were made based on existing data, three different approaches were used to calculate the existing system leakage:

1. Method 1 (Low Estimate): Assumes that SPU is implementing active leakage control measures so that unreported breaks and leaks are detected and fixed at the UARL time frames (i.e., 50 days for mains, and 100-101 days for service connections). This is considered a low estimate of SPU's current leakage rate.
2. Method 2: Assumes that SPU is implementing minimal leakage control measures so that unreported breaks and leaks are detected and fixed at twice the UARL time frames (i.e., 100 days for mains, and 200-202 days for service connections).
3. Method 3: Assumes that SPU is not implementing leakage control measures so that unreported breaks and leaks are detected and fixed at three times the UARL time frames (i.e., 150 days for mains, and 300-303 days for service connections).

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[1] According to Lambert et al (1998), active leakage control BMP's include: 1)regular inspection and sounding of all water main fittings and connections – leakage surveys 2)innovative leakage modeling methods – the bursts and background estimates (BABE) model 3)metering of individual pressure zones 4) district metered areas (DMA) metering – measuring total inflow per day, week or month 5) continuous or intermittent night flow measurements 6) short- period measurements at any time of day 7)temporary or permanent placing of leak noise detectors and loggers 8) pressure modeling 9)controlling pressure close to but greater than the minimum standard of service 10) operating discrete pressure zones configured based on topography 11) limiting maximal pressure levels or surges in pressure 12) nighttime pressure reduction where feasible to reduce losses from small background leaks.

Modification to the IWA method for Reported Leaks and Breaks on Mains and Service Connections

For water mains, the IWA method for calculating reported leaks and breaks is based on a system having 0.2 water main breaks/mile/year. For SPU's 1,800 miles of water mains, this would be equivalent to 360 breaks/year. However, SPU's transmission and distribution system averages only 151 main breaks a year, or 0.08 breaks/mile/year. For this analysis, the value for reported leaks and breaks in water mains was calibrated to reflect SPU's actual break rate.

Similarly, the IWA method estimates that service connections, from the main to the meter, have a leak rate of 3.75 (2.25 + 1.5) leaks/per 1000 services. Since SPU does not distinguish service breaks by which side of the curb stop it occurs on, the calculations were combined to account for SPU's data collection methods. SPU's current leak rate for service connections is 2.8 leaks per 1000 services as shown in Table 2 on page 4. Therefore, 2.8 leaks per 1000 services was used instead of the IWA estimate of 3.75 leaks per 1000 services as the basis for calculating water loss volume from reported leaks and breaks in service connections.

Current Water Losses Volume Calculation – Method 1 (Low Estimate)

Method 1 for calculating SPU's current water loss volume uses the modified IWA calculations with no change to the assumed leak durations. This method represents estimated water losses if SPU initiated and implemented loss control Best Management Practices (BMPs). This estimate is considered a low estimate of SPU's current leakage rate.

Table 4 details the calculations used to determine the volume of leakage from water mains using Method 1. The total leakage from mains for the system was calculated to be 0.539 mgd, and, as shown, most of that leakage can be attributed to the background leakage.

Table 4. Method 1 (Low Estimate) - Water Losses from Main

Leakage Type	Water Main Leakage	
	IWA Rate	SPU Leakage (mgd)
Reported	0.08 breaks/mi/year at 50 gpm for 3 days	0.083
Unreported	0.01 breaks/mi/year @ 25 gpm for 50 days	0.089
Background	8.5 US gal/mi/h	0.367
	TOTAL	**0.539 MGD**

Data regarding actual losses from service connections was used to estimate leak rates, while the IWA duration was used to estimate the volume lost from service connection leaks and breaks. Unreported and Background Leakage was calculated using the IWA method. Table 5 summarizes the estimated water loss from service connections. The estimated volume for reported leaks and breaks totals 2.786 mgd.

Table 5. Method 1 (Low Estimate) – Water Losses from Service Connections		
Leakage Type	Service Connections	
	IWA Rate	SPU Leakage (mgd)
Reported	2.8 leaks/1000 services at 7 gpm for 9 days	0.127
Unreported	1.25 leaks/1000 services at 7 gpm for 101 days	0.638
Background	0.46 gal/service/hour	2.020
	TOTAL	**2.786**

Using the estimates from Tables 4 and 5 above, the combined total loss in mains and service connections using Method 1 is 3.3 mgd. This is less than the 5.6 mgd figure that was estimated in SPU's *2001 Water System Plan Update*. The difference between the calculated UARL and the unmeasured loss figure may be due to an over estimation of the unmeasured losses as mentioned earlier. However, the 3.3 mgd represents the current losses assuming that SPU is implementing an active leakage control program, and SPU currently does not have a proactive leakage control program.

Current Water Losses Volume Calculation – Method 2

Method 2 for calculating SPU's current water loss volume uses the modified IWA method with longer durations for unreported leakage and therefore a higher total leakage volume. SPU currently does not have an active leakage detection program and therefore the unreported leak durations may be longer than those from the IWA method. Method 2 assumes that the unreported leaks for mains and service connections will occur for twice the duration of the IWA method.

As shown in Table 6, the total leakage from mains for the system was calculated to be 0.628 mgd. As shown in Table 7, total leakage from service connections was calculated to be 3.424 mgd with the majority coming from background leakage.

Table 6. Method 2 - Water Losses from Mains		
Leakage Type	Water Main Leakage	
	Rate	SPU Leakage (mgd)
Reported	0.08 breaks/mi/year at 50 gpm for 3 days	0.083
Unreported	0.01 breaks/mi/year @ 25 gpm for **100 days**	0.178
Background	8.5 US gal/mi/h	0.367
	TOTAL	**0.628 MGD**

Table 7. Method 2 – Water Losses from Service Connections		
Leakage Type	Service Connections	
	Rate	SPU Leakage (mgd)
Reported	2.8 leaks/1000 services at 7 gpm for 9 days	0.127
Unreported	1.25 leaks/1000 services at 7 gpm for **202 days**	1.276
Background	0.46 gal/service/hour	2.020
	TOTAL	**3.424**

The total calculated current leakage for the whole system using Method 2 is 4.1 mgd. This is slightly closer to the 5.6 mgd estimated water loss from pipes that was calculated in the *2001 Water System Plan*.

Current Water Losses Volume Calculation – Method 3

Method 3 for calculating SPU's current water loss volume uses the IWA method with even longer durations for unreported leakage and therefore a higher total leakage volume. Method 3 assumes that the unreported leaks for mains and service connections will occur for three times the duration of the IWA method. Therefore, the duration of unreported main leaks is 150 days and service connections unreported leaks occur for 303 days. The calculations of current water loss from mains and service connections using Method 3 are presented in Tables 8 and 9.

Table 8. Method 3 - Water Loss from Mains		
Leakage Type	Water Main Leakage	
	Rate	SPU Leakage (mgd)
Reported	0.08 breaks/mi/year at 50 gpm for 3 days	0.083
Unreported	0.01 breaks/mi/year @ 25 gpm for **150 days**	0.266
Background	8.5 US gal/mi/h	0.367
	TOTAL	**0.716 MGD**

Table 9. Method 3 - Water Loss from Service Connections		
Leakage Type	Service Connections	
	Rate	SPU Leakage (mgd)
Reported	2.8 leaks/1000 services at 7 gpm for 9 days	0.127
Unreported	1.25 leaks/1000 services at 7 gpm for **303 days**	1.914
Background	0.46 gal/service/hour	2.020
	TOTAL	**4.062**

The total estimated volume of leakage using Method 3 is 4.8 mgd.

Projected Future Increase in Reported Leaks and Breaks on Mains

As described in the previous section, three different methods were used to calculate current leakage volumes. In order to project future leakage volumes, assumptions were made on how reported, unreported, and background leakage rates would increase for both service connections and mains. Those assumptions were as follows:

- Reported Leaks/Breaks on Mains: Will increase based on SPU's Waverider Model (described in greater detail below)
- Unreported Leaks/Breaks on Mains: Will increase proportional to reported leaks/breaks on mains.
- Background Leakage on Mains: Will increase proportional to average age of SPU's water mains
- Reported Leaks/Breaks on Service Connections: Will increase/decrease as described below.
- Unreported Leaks/Breaks and Background Leakage on Service Connections: Will increase/decrease proportional to the reported leaks/breaks on service connections.

<u>Projecting Future Reported Leaks/Breaks on Mains</u>

The number of reported leaks and breaks on mains is expected to increase in future years. SPU is currently using a long term planning model called Waverider to help project their long-term water main rehabilitation and replacement needs. Waverider, in part, calculates the number of future failures or main leaks and breaks that will occur, assuming that SPU continues its current practice of replacing water mains at the end of their "economic life." As mentioned earlier, SPU currently experiences 151 reported breaks a year in its water mains. Waverider projects that the number of reported leaks and breaks in water mains will increase from 151 per year at present to a maximum of 3,882 breaks in 2095 as shown in Figure 2.

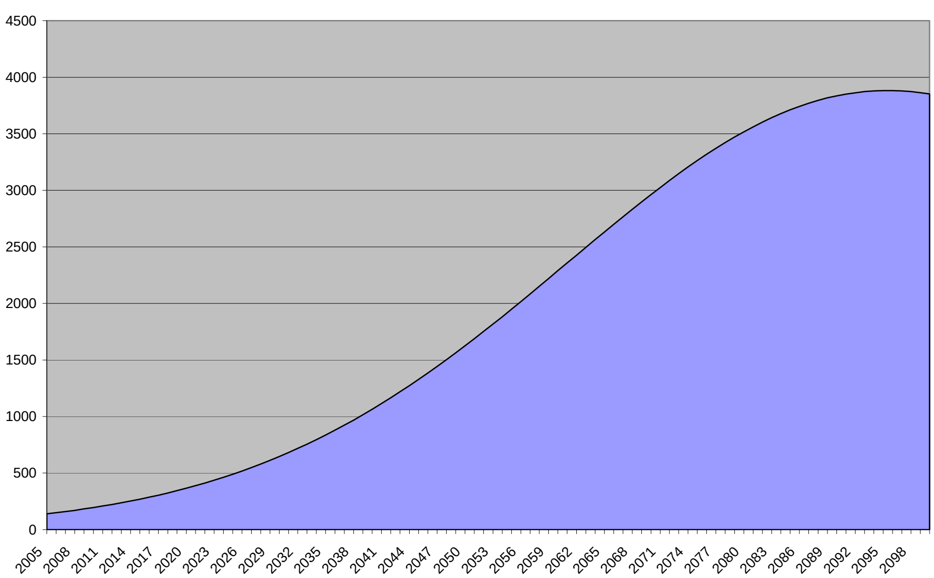

Figure 2. Projected Number of Water Main Breaks per Year

The projection in the number of water main breaks from Waverider was used to project the future water losses from reported water main breaks and leaks.

<u>Projecting Future Reported Leaks/Breaks on Service Connections</u>

Future reported leaks/breaks on service connections were estimated using the following assumptions:

- Reported leaks are expected to decrease from the current rate of 2.8 leaks per 1000 services to 1.5 leaks per 1000 services in the year 2015. SPU has an active service replacement program to replace all non copper services by 2015.
- Beginning in 2015, the reported leaks from service connections will increase to 3.75 leaks per 1000 services (IWA rate) over the economic life of the service connections (estimated at 50 years), in the year 2065.
- The number of reported leaks/breaks on service connections will level off in the year 2065 at the IWA rate of 3.75 leaks per 1000 services.

Projected Leakage

This section presents three different scenarios on how leakage volumes will increase in future years. The three scenarios correspond to the three methods for how current leakage volumes were calculated, as described in an earlier section. The following sections also describe whether the projected leakage is expected to exceed the 10% limit established by DOH. Current demand forecasts from 2006 through 2060 were used to calculate the percentage of water loss in future years. It was assumed that the billed water demand and non-revenue water demand not including leakage would follow the forecast until 2060, and then remain constant from 2060 through 2100.

<u>Method 1</u>

Using the volumes calculated in method 1 and projecting the leakage volumes into the future, the total estimated leakage volume will reach 9.1 mgd in 2095. If the water demand does not drop dramatically over this time, then the leakage rate will not exceed 10% during the time frame of this analysis. Please see attachment 1 for a complete evaluation.

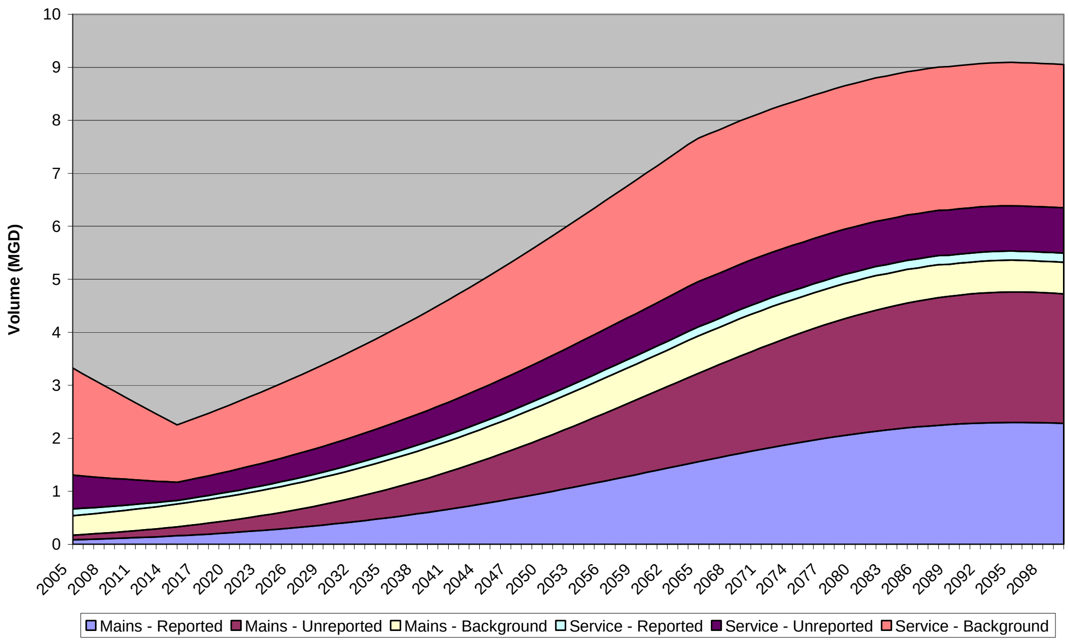

Figure 3. Leak Projections for Method 1

Method 2

Using the volumes calculated in method 2 and projecting the leakage volumes into the future, the total estimated leakage volume will reach 12.4 mgd in 2095. If the water demand does not drop dramatically over this time, then the leakage rate will not exceed 10% during the timeframe of this analysis. Please see attachment 2 for a complete evaluation.

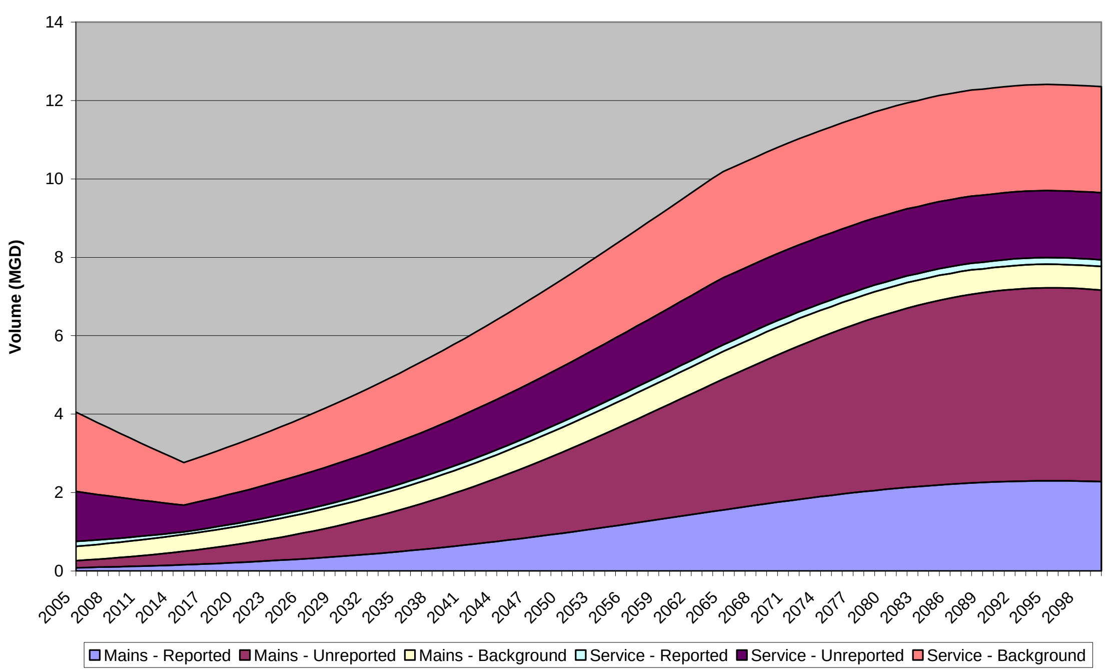

Figure 4. Leak Projections for Method 2

Method 3

Using the volumes calculated in method 3 and projecting the leakage volumes into the future, the total estimated leakage volume will reach 15.7 mgd in 2095. If the water demand does not drop dramatically over this time, then the leakage rate will not exceed 10% during the time frame of this analysis. Please see attachment 3 for a complete evaluation.

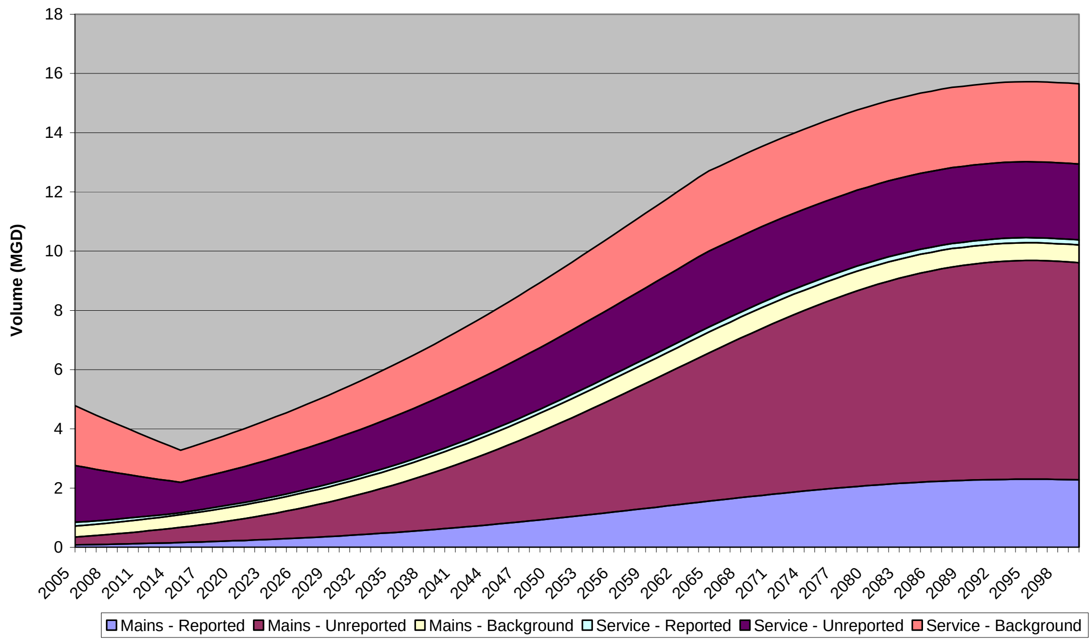

Figure 5. Leak Projections for Method 3

Conclusions

Several conclusions can be drawn from the analysis described above:

- SPU's current water loss due to leaks and breaks in the distribution system is between 3.3mgd to 4.8mgd.
    - Water loss from water mains is between 0.5mgd to 0.7mgd.
    - Water loss from service connections is between 2.8mgd to 4.1mgd.
- SPU's future water loss due to leaks and breaks in the distribution system will reach a maximum of 9mgd to 16mgd around the year 2095. SPU's losses due to leaks and breaks in the distribution system are not expected to exceed DOH's 10% leakage standard.
- Greater accuracy and characterization of the current water losses from water mains and service connections could be attained through a leak detection study and comprehensive water audit.

ATTACHMENT 1

Method 1: Use IWA durations

				Mains			Services									
Year	**Waverider Failures**	**Average Age of System**	**Reported**	**Unreported**	**Background**	**Reported**	**Unreported**	**Background**	**total mains**	**total services**	**TOTAL**	**Rev Water Demand**	**Baseline Non Rev**	**Leakage**	**System Demand**	**Percent Leakage**
			MGD	MGD	MGD	MGD	MGD	MGD				MGD	MGD	MGD	MGD	
			Waverider	*Waverider*	*Age*	*SPU Data*	*% of reported*	*% of reported*								
			(breaks/mi/year @ 50gpm for 3 days)	*(0.01 breaks/mi/year @ 25 gpm for 50 days)*	*(8.5 gal/mi/hour)*	*(leaks/1000 service @ 7gpm 9 days)*	*(1.25 leaks/1000 services @7 gpm for **101 days**)* 101	*(0.46 gal/service/hour)*								
2005	140	59	***0.083***	***0.089***	***0.367***	***0.127***	***0.638***	***2.020***	0.539	2.786	3.325	128.9	7.7	3.3	139.9	2.6%
2006	150	60	0.089	0.095	0.373	0.121	0.608	1.927	0.557	2.657	3.214	127.9	7.6	3.2	138.7	2.5%
2007	160	61	0.095	0.101	0.379	0.116	0.579	1.833	0.576	2.528	3.103	127.0	7.5	3.1	137.6	2.4%
2008	171	62	0.101	0.108	0.386	0.110	0.549	1.740	0.595	2.399	2.994	126.1	7.4	3.0	136.5	2.4%
2009	183	63	0.108	0.116	0.392	0.104	0.520	1.646	0.616	2.270	2.886	125.2	7.3	2.9	135.4	2.3%
2010	196	64	0.116	0.124	0.398	0.098	0.490	1.552	0.638	2.140	2.779	124.3	7.2	2.8	134.3	2.2%
2011	209	65	0.124	0.133	0.404	0.092	0.461	1.459	0.660	2.011	2.672	124.4	7.1	2.7	134.2	2.1%
2012	223	66	0.132	0.141	0.410	0.086	0.431	1.365	0.684	1.882	2.566	124.4	7.0	2.6	134.0	2.1%
2013	237	67	0.140	0.150	0.416	0.080	0.402	1.272	0.707	1.753	2.460	124.4	6.9	2.5	133.8	2.0%
2014	253	68	0.150	0.160	0.423	0.074	0.372	1.178	0.733	1.624	2.357	124.3	6.8	2.4	133.5	1.9%
2015	269	69	0.159	0.171	0.429	***0.068***	0.342	1.082	0.758	1.492	2.251	124.2	6.7	2.3	133.2	1.8%
2016	287	70	0.170	0.182	0.435	0.070	0.352	1.115	0.786	1.537	2.324	124.4	6.7	2.3	133.5	1.9%
2017	305	71	0.180	0.193	0.441	0.072	0.362	1.148	0.815	1.582	2.397	124.6	6.7	2.4	133.8	1.9%
2018	324	72	0.192	0.205	0.447	0.074	0.373	1.180	0.844	1.628	2.472	124.9	6.7	2.5	134.1	2.0%
2019	345	73	0.204	0.219	0.453	0.076	0.383	1.213	0.876	1.673	2.549	125.0	6.7	2.5	134.3	2.0%
2020	366	74	0.217	0.232	0.459	0.079	0.393	1.246	0.908	1.718	2.625	125.2	6.7	2.6	134.6	2.1%
2021	388	75	0.230	0.246	0.465	0.081	0.404	1.278	0.941	1.763	2.703	125.5	6.7	2.7	135.0	2.2%
2022	412	76	0.244	0.261	0.471	0.083	0.414	1.311	0.976	1.808	2.784	125.8	6.7	2.8	135.3	2.2%
2023	437	77	0.259	0.277	0.477	0.085	0.424	1.344	1.013	1.853	2.866	126.1	6.7	2.9	135.7	2.3%
2024	463	78	0.274	0.294	0.483	0.087	0.435	1.376	1.051	1.898	2.949	121.4	6.7	2.9	131.1	2.4%
2025	490	79	0.290	0.311	0.489	0.089	0.445	1.409	1.090	1.943	3.033	121.7	6.7	3.0	131.4	2.5%
2026	519	80	0.307	0.329	0.495	0.091	0.455	1.442	1.132	1.988	3.120	122.1	6.7	3.1	131.9	2.6%
2027	548	81	0.324	0.347	0.502	0.093	0.466	1.474	1.173	2.033	3.206	122.4	6.7	3.2	132.4	2.6%
2028	579	82	0.343	0.367	0.508	0.095	0.476	1.507	1.217	2.078	3.296	122.8	6.7	3.3	132.9	2.7%
2029	612	83	0.362	0.388	0.514	0.097	0.486	1.540	1.264	2.123	3.387	123.2	6.7	3.4	133.3	2.7%
2030	646	84	0.382	0.410	0.520	0.099	0.497	1.572	1.312	2.168	3.480	118.5	6.7	3.5	128.8	2.9%
2031	681	85	0.403	0.432	0.526	0.101	0.507	1.605	1.361	2.213	3.574	119.6	6.7	3.6	129.9	3.0%
2032	718	86	0.425	0.455	0.532	0.103	0.517	1.638	1.412	2.258	3.671	120.7	6.7	3.7	131.1	3.0%
2033	756	87	0.447	0.479	0.538	0.105	0.528	1.671	1.465	2.303	3.768	121.8	6.7	3.8	132.3	3.1%
2034	795	88	0.470	0.504	0.544	0.107	0.538	1.703	1.519	2.348	3.867	122.9	6.7	3.9	133.5	3.1%
2035	836	89	0.495	0.530	0.550	0.109	0.548	1.736	1.575	2.394	3.969	119.1	6.7	4.0	129.8	3.3%
2036	879	90	0.520	0.557	0.555	0.111	0.559	1.769	1.633	2.439	4.072	120.3	6.7	4.1	131.1	3.4%
2037	923	91	0.546	0.585	0.560	0.114	0.569	1.801	1.692	2.484	4.175	121.5	6.7	4.2	132.4	3.4%
2038	968	91	0.573	0.614	0.566	0.116	0.579	1.834	1.753	2.529	4.281	122.7	6.7	4.3	133.8	3.5%
2039	1015	92	0.601	0.644	0.571	0.118	0.589	1.867	1.816	2.574	4.389	124.0	6.7	4.4	135.2	3.5%
2040	1064	93	0.630	0.675	0.577	0.120	0.600	1.899	1.881	2.619	4.500	120.3	6.7	4.5	131.6	3.7%
2041	1114	94	0.659	0.706	0.582	0.122	0.610	1.932	1.948	2.664	4.611	121.6	6.7	4.6	133.0	3.8%
2042	1165	95	0.689	0.739	0.587	0.124	0.620	1.965	2.015	2.709	4.724	122.9	6.7	4.7	134.4	3.8%
2043	1218	96	0.721	0.772	0.593	0.126	0.631	1.997	2.086	2.754	4.840	124.2	6.7	4.8	135.8	3.9%
2044	1272	97	0.753	0.807	0.598	0.128	0.641	2.030	2.158	2.799	4.957	125.6	6.7	5.0	137.3	3.9%
2045	1328	98	0.786	0.842	0.604	0.130	0.651	2.063	2.232	2.844	5.076	121.9	6.7	5.1	133.8	4.2%
2046	1385	99	0.820	0.878	0.610	0.132	0.662	2.095	2.307	2.889	5.197	123.3	6.7	5.2	135.3	4.2%
2047	1443	99	0.854	0.915	0.616	0.134	0.672	2.128	2.385	2.934	5.319	124.7	6.7	5.3	136.8	4.3%
2048	1503	100	0.889	0.953	0.622	0.136	0.682	2.161	2.464	2.979	5.443	126.1	6.7	5.4	138.3	4.3%
2049	1563	101	0.925	0.991	0.628	0.138	0.693	2.193	2.544	3.024	5.568	127.5	6.7	5.6	139.8	4.4%
2050	1625	102	0.962	1.030	0.633	0.140	0.703	2.226	2.625	3.069	5.695	128.9	6.7	5.7	141.3	4.4%
2051	1688	103	0.999	1.070	0.638	0.142	0.713	2.259	2.707	3.114	5.822	130.3	6.7	5.8	142.9	4.5%
2052	1752	104	1.037	1.111	0.644	0.144	0.724	2.291	2.792	3.160	5.951	131.7	6.7	6.0	144.4	4.5%
2053	1817	105	1.075	1.152	0.650	0.147	0.734	2.324	2.877	3.205	6.082	133.1	6.7	6.1	146.0	4.6%
2054	1882	106	1.114	1.193	0.655	0.149	0.744	2.357	2.962	3.250	6.211	134.6	6.7	6.2	147.5	4.6%
2055	1949	107	1.153	1.236	0.659	0.151	0.755	2.389	3.048	3.295	6.343	136.0	6.7	6.3	149.1	4.7%
2056	2016	107	1.193	1.278	0.664	0.153	0.765	2.422	3.135	3.340	6.475	137.4	6.7	6.5	150.7	4.7%
2057	2084	108	1.233	1.321	0.669	0.155	0.775	2.455	3.224	3.385	6.609	138.9	6.7	6.6	152.3	4.8%
2058	2152	109	1.274	1.364	0.673	0.157	0.786	2.488	3.311	3.430	6.741	140.4	6.7	6.7	153.9	4.8%
2059	2220	109	1.314	1.408	0.674	0.159	0.796	2.520	3.396	3.475	6.871	141.8	6.7	6.9	155.5	4.8%
2060	2289	110	1.355	1.451	0.680	0.161	0.806	2.553	3.486	3.520	7.006	143.3	6.7	7.0	157.1	4.9%
2061	2358	111	1.395	1.495	0.684	0.163	0.817	2.586	3.575	3.565	7.140	143.3	6.7	7.1	157.2	5.0%
2062	2426	111	1.436	1.538	0.690	0.165	0.827	2.618	3.663	3.610	7.274	143.3	6.7	7.3	157.3	5.1%
2063	2495	112	1.476	1.582	0.695	0.167	0.837	2.651	3.754	3.655	7.409	143.3	6.7	7.4	157.5	5.2%
2064	2564	113	1.517	1.626	0.701	0.169	0.848	2.684	3.844	3.700	7.544	143.3	6.7	7.5	157.6	5.3%
2065	2632	114	1.558	1.669	0.707	***0.171***	0.855	2.706	3.933	3.731	7.664	143.3	6.7	7.7	157.7	5.3%
2066	2699	114	1.597	1.711	0.704	0.171	0.855	2.706	4.013	3.731	7.743	143.3	6.7	7.7	157.8	5.4%
2067	2766	113	1.637	1.754	0.702	0.171	0.855	2.706	4.092	3.731	7.823	143.3	6.7	7.8	157.9	5.5%
2068	2832	114	1.676	1.796	0.706	0.171	0.855	2.706	4.178	3.731	7.908	143.3	6.7	7.9	158.0	5.5%
2069	2898	114	1.715	1.837	0.708	0.171	0.855	2.706	4.261	3.731	7.992	143.3	6.7	8.0	158.1	5.6%
2070	2962	114	1.753	1.878	0.706	0.171	0.855	2.706	4.337	3.731	8.068	143.3	6.7	8.1	158.1	5.6%
2071	3025	113	1.790	1.918	0.701	0.171	0.855	2.706	4.409	3.731	8.140	143.3	6.7	8.1	158.2	5.7%
2072	3087	113	1.827	1.957	0.700	0.171	0.855	2.706	4.484	3.731	8.215	143.3	6.7	8.2	158.3	5.7%
2073	3147	112	1.862	1.995	0.692	0.171	0.855	2.706	4.550	3.731	8.281	143.3	6.7	8.3	158.3	5.8%
2074	3206	110	1.897	2.033	0.683	0.171	0.855	2.706	4.613	3.731	8.344	143.3	6.7	8.3	158.4	5.8%
2075	3263	109	1.931	2.069	0.674	0.171	0.855	2.706	4.674	3.731	8.405	143.3	6.7	8.4	158.5	5.9%
2076	3318	109	1.964	2.104	0.674	0.171	0.855	2.706	4.741	3.731	8.472	143.3	6.7	8.5	158.5	5.9%
2077	3371	108	1.995	2.137	0.669	0.171	0.855	2.706	4.801	3.731	8.532	143.3	6.7	8.5	158.6	6.0%
2078	3422	108	2.025	2.170	0.668	0.171	0.855	2.706	4.862	3.731	8.593	143.3	6.7	8.6	158.7	6.0%
2079	3471	108	2.054	2.201	0.667	0.171	0.855	2.706	4.921	3.731	8.652	143.3	6.7	8.7	158.7	6.0%
2080	3517	106	2.081	2.230	0.657	0.171	0.855	2.706	4.968	3.731	8.699	143.3	6.7	8.7	158.8	6.1%
2081	3561	106	2.107	2.258	0.655	0.171	0.855	2.706	5.021	3.731	8.751	143.3	6.7	8.8	158.8	6.1%
2082	3603	105	2.132	2.284	0.653	0.171	0.855	2.706	5.070	3.731	8.800	143.3	6.7	8.8	158.9	6.1%
2083	3642	103	2.155	2.309	0.639	0.171	0.855	2.706	5.104	3.731	8.835	143.3	6.7	8.8	158.9	6.2%
2084	3678	103	2.177	2.332	0.638	0.171	0.855	2.706	5.146	3.731	8.877	143.3	6.7	8.9	158.9	6.2%
2085	3712	103	2.197	2.354	0.636	0.171	0.855	2.706	5.187	3.731	8.918	143.3	6.7	8.9	159.0	6.2%
2086	3742	101	2.214	2.373	0.626	0.171	0.855	2.706	5.213	3.731	8.944	143.3	6.7	8.9	159.0	6.2%
2087	3770	101	2.231	2.390	0.626	0.171	0.855	2.706	5.247	3.731	8.978	143.3	6.7	9.0	159.0	6.3%
2088	3795	101	2.246	2.406	0.623	0.171	0.855	2.706	5.275	3.731	9.006	143.3	6.7	9.0	159.1	6.3%
2089	3817	98	2.259	2.420	0.604	0.171	0.855	2.706	5.283	3.731	9.014	143.3	6.7	9.0	159.1	6.3%
2090	3835	98	2.269	2.432	0.605	0.171	0.855	2.706	5.306	3.731	9.036	143.3	6.7	9.0	159.1	6.3%
2091	3851	97	2.279	2.442	0.601	0.171	0.855	2.706	5.322	3.731	9.053	143.3	6.7	9.1	159.1	6.3%
2092	3863	98	2.286	2.449	0.605	0.171	0.855	2.706	5.340	3.731	9.071	143.3	6.7	9.1	159.1	6.3%
2093	3873	98	2.292	2.456	0.604	0.171	0.855	2.706	5.351	3.731	9.082	143.3	6.7	9.1	159.1	6.3%
2094	3879	98	2.296	2.459	0.603	0.171	0.855	2.706	5.358	3.731	9.089	143.3	6.7	9.1	159.1	6.3%
2095	3882	97	2.297	2.461	0.603	0.171	0.855	2.706	5.361	3.731	9.092	143.3	6.7	9.1	159.2	6.3%
2096	3882	97	2.297	2.461	0.598	0.171	0.855	2.706	5.357	3.731	9.088	143.3	6.7	9.1	159.1	6.3%
2097	3879	96	2.296	2.459	0.596	0.171	0.855	2.706	5.351	3.731	9.082	143.3	6.7	9.1	159.1	6.3%
2098	3873	96	2.292	2.456	0.593	0.171	0.855	2.706	5.340	3.731	9.071	143.3	6.7	9.1	159.1	6.3%
2099	3864	97	2.287	2.450	0.597	0.171	0.855	2.706	5.334	3.731	9.065	143.3	6.7	9.1	159.1	6.3%
2100	3852	97	2.280	2.442	0.601	0.171	0.855	2.706	5.323	3.731	9.054	143.3	6.7	9.1	159.1	6.3%

ATTACHMENT 2

Method 2: Use 2 times IWA durations for unreported

			Mains			Services										
Year	**Waverider Failures**	**Average Age of System**	**Reported**	**Unreported**	**Background**	**Reported**	**Unreported**	**Background**	**total mains**	**total services**	**TOTAL**	**Rev Water Demand**	**Baseline Non Rev**	**Leakage**	**System Demand**	**Percent Leakage**
			MGD	MGD	MGD	MGD	MGD	MGD	MGD	MGD	MGD	MGD	MGD	MGD	MGD	
			Waverider	*Waverider*	*Age*	*SPU Data*	*% of reported*	*% of reported*								
			(breaks/mi/year @ 50gpm for 3 days)	*(0.01 breaks/mi/year @ 25 gpm for* ***100 days****)*	*(8.5 gal/mi/hour)*	*(leaks/1000 service @ 7gpm 9 days)*	*(1.25 leaks/1000 services @7 gpm for* ***202 days****)*	*(0.46 gal/service/hour)*								
							202									
2005	140	59	***0.083***	***0.178***	***0.367***	***0.127***	***1.276***	***2.020***	0.628	3.424	4.051	128.9	6.9	4.1	139.9	3.1%
2006	150	60	0.089	0.190	0.373	0.121	1.217	1.927	0.652	3.265	3.917	127.9	6.9	3.9	138.7	3.1%
2007	160	61	0.095	0.203	0.379	0.116	1.158	1.833	0.677	3.107	3.784	127.0	6.8	3.8	137.6	3.0%
2008	171	62	0.101	0.217	0.386	0.110	1.099	1.740	0.704	2.948	3.652	126.1	6.7	3.7	136.5	2.9%
2009	183	63	0.108	0.232	0.392	0.104	1.040	1.646	0.732	2.789	3.521	125.2	6.7	3.5	135.4	2.8%
2010	196	64	0.116	0.249	0.398	0.098	0.981	1.552	0.763	2.631	3.393	124.3	6.6	3.4	134.3	2.7%
2011	209	65	0.124	0.265	0.404	0.092	0.921	1.459	0.793	2.472	3.265	124.4	6.5	3.3	134.2	2.6%
2012	223	66	0.132	0.283	0.410	0.086	0.862	1.365	0.825	2.313	3.139	124.4	6.5	3.1	134.0	2.5%
2013	237	67	0.140	0.301	0.416	0.080	0.803	1.272	0.857	2.155	3.012	124.4	6.4	3.0	133.8	2.4%
2014	253	68	0.150	0.321	0.423	0.074	0.744	1.178	0.893	1.996	2.889	124.3	6.3	2.9	133.5	2.3%
2015	269	69	0.159	0.341	0.429	***0.068***	0.684	1.082	0.929	1.834	2.763	124.2	6.2	2.8	133.2	2.2%
2016	287	70	0.170	0.364	0.435	0.070	0.704	1.115	0.968	1.890	2.858	124.4	6.2	2.9	133.5	2.3%
2017	305	71	0.180	0.387	0.441	0.072	0.725	1.148	1.008	1.945	2.953	124.6	6.2	3.0	133.8	2.4%
2018	324	72	0.192	0.411	0.447	0.074	0.746	1.180	1.049	2.000	3.050	124.9	6.2	3.0	134.1	2.4%
2019	345	73	0.204	0.437	0.453	0.076	0.766	1.213	1.095	2.056	3.150	125.0	6.2	3.2	134.4	2.5%
2020	366	74	0.217	0.464	0.459	0.079	0.787	1.246	1.140	2.111	3.251	125.2	6.2	3.3	134.7	2.6%
2021	388	75	0.230	0.492	0.465	0.081	0.807	1.278	1.187	2.166	3.353	125.5	6.2	3.4	135.1	2.7%
2022	412	76	0.244	0.522	0.471	0.083	0.828	1.311	1.237	2.222	3.459	125.8	6.2	3.5	135.5	2.7%
2023	437	77	0.259	0.554	0.477	0.085	0.849	1.344	1.290	2.277	3.567	126.1	6.2	3.6	135.9	2.8%
2024	463	78	0.274	0.587	0.483	0.087	0.869	1.376	1.344	2.333	3.677	121.4	6.2	3.7	131.3	3.0%
2025	490	79	0.290	0.621	0.489	0.089	0.890	1.409	1.401	2.388	3.789	121.7	6.2	3.8	131.7	3.1%
2026	519	80	0.307	0.658	0.495	0.091	0.911	1.442	1.461	2.443	3.904	122.1	6.2	3.9	132.2	3.2%
2027	548	81	0.324	0.695	0.502	0.093	0.931	1.474	1.521	2.499	4.020	122.4	6.2	4.0	132.7	3.3%
2028	579	82	0.343	0.734	0.508	0.095	0.952	1.507	1.585	2.554	4.139	122.8	6.2	4.1	133.2	3.4%
2029	612	83	0.362	0.776	0.514	0.097	0.973	1.540	1.652	2.609	4.262	123.2	6.2	4.3	133.7	3.5%
2030	646	84	0.382	0.819	0.520	0.099	0.993	1.572	1.721	2.665	4.386	118.5	6.2	4.4	129.2	3.7%
2031	681	85	0.403	0.864	0.526	0.101	1.014	1.605	1.793	2.720	4.513	119.6	6.2	4.5	130.3	3.8%
2032	718	86	0.425	0.910	0.532	0.103	1.035	1.638	1.868	2.776	4.643	120.7	6.2	4.6	131.6	3.8%
2033	756	87	0.447	0.959	0.538	0.105	1.055	1.671	1.944	2.831	4.775	121.8	6.2	4.8	132.8	3.9%
2034	795	88	0.470	1.008	0.544	0.107	1.076	1.703	2.023	2.886	4.909	122.9	6.2	4.9	134.0	4.0%
2035	836	89	0.495	1.060	0.550	0.109	1.096	1.736	2.105	2.942	5.047	119.1	6.2	5.0	130.3	4.2%
2036	879	90	0.520	1.115	0.555	0.111	1.117	1.769	2.190	2.997	5.187	120.3	6.2	5.2	131.7	4.3%
2037	923	91	0.546	1.170	0.560	0.114	1.138	1.801	2.277	3.053	5.329	121.5	6.2	5.3	133.1	4.4%
2038	968	91	0.573	1.228	0.566	0.116	1.158	1.834	2.366	3.108	5.474	122.7	6.2	5.5	134.5	4.5%
2039	1015	92	0.601	1.287	0.571	0.118	1.179	1.867	2.459	3.163	5.622	124.0	6.2	5.6	135.9	4.5%
2040	1064	93	0.630	1.349	0.577	0.120	1.200	1.899	2.556	3.219	5.775	120.3	6.2	5.8	132.3	4.8%
2041	1114	94	0.659	1.413	0.582	0.122	1.220	1.932	2.654	3.274	5.928	121.6	6.2	5.9	133.8	4.9%
2042	1165	95	0.689	1.477	0.587	0.124	1.241	1.965	2.754	3.329	6.083	122.9	6.2	6.1	135.2	4.9%
2043	1218	96	0.721	1.545	0.593	0.126	1.262	1.997	2.858	3.385	6.243	124.2	6.2	6.2	136.7	5.0%
2044	1272	97	0.753	1.613	0.598	0.128	1.282	2.030	2.964	3.440	6.404	125.6	6.2	6.4	138.2	5.1%
2045	1328	98	0.786	1.684	0.604	0.130	1.303	2.063	3.074	3.496	6.569	121.9	6.2	6.6	134.7	5.4%
2046	1385	99	0.820	1.756	0.610	0.132	1.323	2.095	3.186	3.551	6.737	123.3	6.2	6.7	136.3	5.5%
2047	1443	99	0.854	1.830	0.616	0.134	1.344	2.128	3.299	3.606	6.906	124.7	6.2	6.9	137.8	5.5%
2048	1503	100	0.889	1.906	0.622	0.136	1.365	2.161	3.417	3.662	7.079	126.1	6.2	7.1	139.4	5.6%
2049	1563	101	0.925	1.982	0.628	0.138	1.385	2.193	3.535	3.717	7.252	127.5	6.2	7.3	141.0	5.7%
2050	1625	102	0.962	2.061	0.633	0.140	1.406	2.226	3.656	3.772	7.428	128.9	6.2	7.4	142.5	5.8%
2051	1688	103	0.999	2.141	0.638	0.142	1.427	2.259	3.778	3.828	7.606	130.3	6.2	7.6	144.1	5.8%
2052	1752	104	1.037	2.222	0.644	0.144	1.447	2.291	3.903	3.883	7.786	131.7	6.2	7.8	145.7	5.9%
2053	1817	105	1.075	2.304	0.650	0.147	1.468	2.324	4.029	3.939	7.968	133.1	6.2	8.0	147.3	6.0%
2054	1882	106	1.114	2.387	0.655	0.149	1.489	2.357	4.155	3.994	8.149	134.6	6.2	8.1	148.9	6.1%
2055	1949	107	1.153	2.472	0.659	0.151	1.509	2.389	4.284	4.049	8.334	136.0	6.2	8.3	150.6	6.1%
2056	2016	107	1.193	2.556	0.664	0.153	1.530	2.422	4.413	4.105	8.518	137.4	6.2	8.5	152.2	6.2%
2057	2084	108	1.233	2.643	0.669	0.155	1.551	2.455	4.545	4.160	8.705	138.9	6.2	8.7	153.8	6.3%
2058	2152	109	1.274	2.729	0.673	0.157	1.571	2.488	4.675	4.215	8.891	140.4	6.2	8.9	155.5	6.3%
2059	2220	109	1.314	2.815	0.674	0.159	1.592	2.520	4.803	4.271	9.074	141.8	6.2	9.1	157.1	6.4%
2060	2289	110	1.355	2.903	0.680	0.161	1.612	2.553	4.937	4.326	9.263	143.3	6.2	9.3	158.8	6.5%
2061	2358	111	1.395	2.990	0.684	0.163	1.633	2.586	5.070	4.382	9.452	143.3	6.2	9.5	159.0	6.6%
2062	2426	111	1.436	3.076	0.690	0.165	1.654	2.618	5.202	4.437	9.639	143.3	6.2	9.6	159.2	6.7%
2063	2495	112	1.476	3.164	0.695	0.167	1.674	2.651	5.336	4.492	9.828	143.3	6.2	9.8	159.4	6.9%
2064	2564	113	1.517	3.251	0.701	0.169	1.695	2.684	5.470	4.548	10.017	143.3	6.2	10.0	159.6	7.0%
2065	2632	114	1.558	3.338	0.707	***0.171***	1.709	2.706	5.602	4.585	10.187	143.3	6.2	10.2	159.7	7.1%
2066	2699	114	1.597	3.423	0.704	0.171	1.709	2.706	5.724	4.585	10.309	143.3	6.2	10.3	159.9	7.2%
2067	2766	113	1.637	3.508	0.702	0.171	1.709	2.706	5.846	4.585	10.432	143.3	6.2	10.4	160.0	7.3%
2068	2832	114	1.676	3.591	0.706	0.171	1.709	2.706	5.973	4.585	10.559	143.3	6.2	10.6	160.1	7.4%
2069	2898	114	1.715	3.675	0.708	0.171	1.709	2.706	6.098	4.585	10.684	143.3	6.2	10.7	160.2	7.5%
2070	2962	114	1.753	3.756	0.706	0.171	1.709	2.706	6.215	4.585	10.801	143.3	6.2	10.8	160.3	7.5%
2071	3025	113	1.790	3.836	0.701	0.171	1.709	2.706	6.327	4.585	10.912	143.3	6.2	10.9	160.5	7.6%
2072	3087	113	1.827	3.915	0.700	0.171	1.709	2.706	6.442	4.585	11.027	143.3	6.2	11.0	160.6	7.7%
2073	3147	112	1.862	3.991	0.692	0.171	1.709	2.706	6.545	4.585	11.131	143.3	6.2	11.1	160.7	7.8%
2074	3206	110	1.897	4.066	0.683	0.171	1.709	2.706	6.646	4.585	11.231	143.3	6.2	11.2	160.8	7.8%
2075	3263	109	1.931	4.138	0.674	0.171	1.709	2.706	6.743	4.585	11.328	143.3	6.2	11.3	160.9	7.9%
2076	3318	109	1.964	4.208	0.674	0.171	1.709	2.706	6.845	4.585	11.430	143.3	6.2	11.4	161.0	8.0%
2077	3371	108	1.995	4.275	0.669	0.171	1.709	2.706	6.939	4.585	11.524	143.3	6.2	11.5	161.1	8.0%
2078	3422	108	2.025	4.339	0.668	0.171	1.709	2.706	7.032	4.585	11.618	143.3	6.2	11.6	161.2	8.1%
2079	3471	108	2.054	4.402	0.667	0.171	1.709	2.706	7.122	4.585	11.708	143.3	6.2	11.7	161.3	8.2%
2080	3517	106	2.081	4.460	0.657	0.171	1.709	2.706	7.198	4.585	11.783	143.3	6.2	11.8	161.3	8.2%
2081	3561	106	2.107	4.516	0.655	0.171	1.709	2.706	7.278	4.585	11.864	143.3	6.2	11.9	161.4	8.3%
2082	3603	105	2.132	4.569	0.653	0.171	1.709	2.706	7.354	4.585	11.939	143.3	6.2	11.9	161.5	8.3%
2083	3642	103	2.155	4.618	0.639	0.171	1.709	2.706	7.413	4.585	11.999	143.3	6.2	12.0	161.5	8.4%
2084	3678	103	2.177	4.664	0.638	0.171	1.709	2.706	7.478	4.585	12.064	143.3	6.2	12.1	161.6	8.4%
2085	3712	103	2.197	4.707	0.636	0.171	1.709	2.706	7.540	4.585	12.126	143.3	6.2	12.1	161.7	8.5%
2086	3742	101	2.214	4.745	0.626	0.171	1.709	2.706	7.586	4.585	12.171	143.3	6.2	12.2	161.7	8.5%
2087	3770	101	2.231	4.781	0.626	0.171	1.709	2.706	7.637	4.585	12.223	143.3	6.2	12.2	161.8	8.5%
2088	3795	101	2.246	4.812	0.623	0.171	1.709	2.706	7.681	4.585	12.267	143.3	6.2	12.3	161.8	8.6%
2089	3817	98	2.259	4.840	0.604	0.171	1.709	2.706	7.703	4.585	12.288	143.3	6.2	12.3	161.8	8.6%
2090	3835	98	2.269	4.863	0.605	0.171	1.709	2.706	7.737	4.585	12.323	143.3	6.2	12.3	161.9	8.6%
2091	3851	97	2.279	4.883	0.601	0.171	1.709	2.706	7.763	4.585	12.349	143.3	6.2	12.3	161.9	8.6%
2092	3863	98	2.286	4.899	0.605	0.171	1.709	2.706	7.790	4.585	12.375	143.3	6.2	12.4	161.9	8.6%
2093	3873	98	2.292	4.911	0.604	0.171	1.709	2.706	7.807	4.585	12.392	143.3	6.2	12.4	161.9	8.6%
2094	3879	98	2.296	4.919	0.603	0.171	1.709	2.706	7.818	4.585	12.403	143.3	6.2	12.4	161.9	8.7%
2095	3882	97	2.297	4.923	0.603	0.171	1.709	2.706	7.823	4.585	12.408	143.3	6.2	12.4	162.0	8.7%
2096	3882	97	2.297	4.923	0.598	0.171	1.709	2.706	7.819	4.585	12.404	143.3	6.2	12.4	162.0	8.7%
2097	3879	96	2.296	4.919	0.596	0.171	1.709	2.706	7.810	4.585	12.396	143.3	6.2	12.4	161.9	8.6%
2098	3873	96	2.292	4.911	0.593	0.171	1.709	2.706	7.796	4.585	12.381	143.3	6.2	12.4	161.9	8.6%
2099	3864	97	2.287	4.900	0.597	0.171	1.709	2.706	7.784	4.585	12.369	143.3	6.2	12.4	161.9	8.6%
2100	3852	97	2.280	4.885	0.601	0.171	1.709	2.706	7.766	4.585	12.351	143.3	6.2	12.4	161.9	8.6%

ATTACHMENT 3

Method 3: Use 3 times IWA durations for unreported

Year	Waverider Failures	Average Age of System	Mains Reported	Mains Unreported	Mains Background	Services Reported	Services Unreported	Services Background	total mains	total services	TOTAL	Rev Water Demand	Baseline Non Rev	Leakage	System Demand	Percent Leakage
			MGD	MGD	MGD	MGD	MGD	MGD	MGD	MGD	MGD	MGD	MGD	MGD	MGD	
			Waverider	*Waverider*	*Age*	*SPU Data*	*% of reported*	*% of reported*								
			(breaks/mi/year @ 50gpm for 3 days)	*(0.01 breaks/mi/year @ 25 gpm for* ***150 days****)*	*(8.5 gal/mi/hour)*	*(leaks/1000 service @ 7gpm 9 days)*	*(1.25 leaks/1000 services @ 7 gpm for* ***303 days****)* 303	*(0.46 gal/service/hour)*								
2005	140	59	***0.083***	***0.266***	***0.367***	***0.127***	**1.914**	***2.020***	0.716	4.062	4.778	128.9	6.2	4.8	139.9	3.4%
2006	150	60	0.089	0.285	0.373	0.121	1.825	1.927	0.747	3.874	4.621	127.9	6.2	4.6	138.7	3.3%
2007	160	61	0.095	0.304	0.379	0.116	1.737	1.833	0.778	3.685	4.464	127.0	6.1	4.5	137.6	3.2%
2008	171	62	0.101	0.325	0.386	0.110	1.648	1.740	0.812	3.497	4.309	126.1	6.1	4.3	136.5	3.2%
2009	183	63	0.108	0.348	0.392	0.104	1.559	1.646	0.848	3.309	4.157	125.2	6.0	4.2	135.4	3.1%
2010	196	64	0.116	0.373	0.398	0.098	1.471	1.552	0.887	3.121	4.008	124.3	6.0	4.0	134.3	3.0%
2011	209	65	0.124	0.398	0.404	0.092	1.382	1.459	0.925	2.933	3.858	124.4	5.9	3.9	134.2	2.9%
2012	223	66	0.132	0.424	0.410	0.086	1.293	1.365	0.967	2.745	3.711	124.4	5.9	3.7	134.0	2.8%
2013	237	67	0.140	0.451	0.416	0.080	1.205	1.272	1.007	2.556	3.564	124.4	5.8	3.6	133.8	2.7%
2014	253	68	0.150	0.481	0.423	0.074	1.116	1.178	1.053	2.368	3.422	124.3	5.8	3.4	133.5	2.6%
2015	269	69	0.159	0.512	0.429	***0.068***	1.025	1.082	1.100	2.176	**3.276**	124.2	5.7	3.3	133.2	2.5%
2016	287	70	0.170	0.546	0.435	0.070	1.056	1.115	1.150	2.242	3.392	124.4	5.7	3.4	133.5	2.5%
2017	305	71	0.180	0.580	0.441	0.072	1.087	1.148	1.201	2.307	3.509	124.6	5.7	3.5	133.9	2.6%
2018	324	72	0.192	0.616	0.447	0.074	1.118	1.180	1.255	2.373	3.628	124.9	5.7	3.6	134.2	2.7%
2019	345	73	0.204	0.656	0.453	0.076	1.149	1.213	1.313	2.439	3.752	125.0	5.7	3.8	134.5	2.8%
2020	366	74	0.217	0.696	0.459	0.079	1.180	1.246	1.372	2.504	3.876	125.2	5.7	3.9	134.8	2.9%
2021	388	75	0.230	0.738	0.465	0.081	1.211	1.278	1.433	2.570	4.003	125.5	5.7	4.0	135.2	3.0%
2022	412	76	0.244	0.784	0.471	0.083	1.242	1.311	1.499	2.636	4.135	125.8	5.7	4.1	135.7	3.0%
2023	437	77	0.259	0.831	0.477	0.085	1.273	1.344	1.567	2.702	4.269	126.1	5.7	4.3	136.1	3.1%
2024	463	78	0.274	0.881	0.483	0.087	1.304	1.376	1.638	2.767	4.405	121.4	5.7	4.4	131.5	3.3%
2025	490	79	0.290	0.932	0.489	0.089	1.335	1.409	1.711	2.833	4.544	121.7	5.7	4.5	131.9	3.4%
2026	519	80	0.307	0.987	0.495	0.091	1.366	1.442	1.790	2.899	4.688	122.1	5.7	4.7	132.5	3.5%
2027	548	81	0.324	1.042	0.502	0.093	1.397	1.474	1.868	2.964	4.833	122.4	5.7	4.8	133.0	3.6%
2028	579	82	0.343	1.101	0.508	0.095	1.428	1.507	1.952	3.030	4.982	122.8	5.7	5.0	133.5	3.7%
2029	612	83	0.362	1.164	0.514	0.097	1.459	1.540	2.040	3.096	5.136	123.2	5.7	5.1	134.0	3.8%
2030	646	84	0.382	1.229	0.520	0.099	1.490	1.572	2.131	3.161	5.292	118.5	5.7	5.3	129.6	4.1%
2031	681	85	0.403	1.295	0.526	0.101	1.521	1.605	2.224	3.227	5.452	119.6	5.7	5.5	130.8	4.2%
2032	718	86	0.425	1.366	0.532	0.103	1.552	1.638	2.323	3.293	5.616	120.7	5.7	5.6	132.0	4.3%
2033	756	87	0.447	1.438	0.538	0.105	1.583	1.671	2.424	3.359	5.782	121.8	5.7	5.8	133.3	4.3%
2034	795	88	0.470	1.512	0.544	0.107	1.614	1.703	2.527	3.424	5.951	122.9	5.7	6.0	134.6	4.4%
2035	836	89	0.495	1.590	0.550	0.109	1.645	1.736	2.635	3.490	6.125	119.1	5.7	6.1	130.9	4.7%
2036	879	90	0.520	1.672	0.555	0.111	1.676	1.769	2.748	3.556	6.303	120.3	5.7	6.3	132.3	4.8%
2037	923	91	0.546	1.756	0.560	0.114	1.707	1.801	2.862	3.621	6.483	121.5	5.7	6.5	133.7	4.8%
2038	968	91	0.573	1.841	0.566	0.116	1.738	1.834	2.980	3.687	6.667	122.7	5.7	6.7	135.1	4.9%
2039	1015	92	0.601	1.931	0.571	0.118	1.768	1.867	3.103	3.753	6.856	124.0	5.7	6.9	136.6	5.0%
2040	1064	93	0.630	2.024	0.577	0.120	1.799	1.899	3.231	3.818	7.049	120.3	5.7	7.0	133.1	5.3%
2041	1114	94	0.659	2.119	0.582	0.122	1.830	1.932	3.360	3.884	7.244	121.6	5.7	7.2	134.6	5.4%
2042	1165	95	0.689	2.216	0.587	0.124	1.861	1.965	3.493	3.950	7.442	122.9	5.7	7.4	136.1	5.5%
2043	1218	96	0.721	2.317	0.593	0.126	1.892	1.997	3.631	4.016	7.646	124.2	5.7	7.6	137.6	5.6%
2044	1272	97	0.753	2.420	0.598	0.128	1.923	2.030	3.771	4.081	7.852	125.6	5.7	7.9	139.2	5.6%
2045	1328	98	0.786	2.526	0.604	0.130	1.954	2.063	3.916	4.147	8.063	121.9	5.7	8.1	135.7	5.9%
2046	1385	99	0.820	2.634	0.610	0.132	1.985	2.095	4.064	4.213	8.276	123.3	5.7	8.3	137.3	6.0%
2047	1443	99	0.854	2.745	0.616	0.134	2.016	2.128	4.214	4.278	8.493	124.7	5.7	8.5	138.9	6.1%
2048	1503	100	0.889	2.859	0.622	0.136	2.047	2.161	4.370	4.344	8.714	126.1	5.7	8.7	140.5	6.2%
2049	1563	101	0.925	2.973	0.628	0.138	2.078	2.193	4.526	4.410	8.936	127.5	5.7	8.9	142.1	6.3%
2050	1625	102	0.962	3.091	0.633	0.140	2.109	2.226	4.686	4.475	9.161	128.9	5.7	9.2	143.8	6.4%
2051	1688	103	0.999	3.211	0.638	0.142	2.140	2.259	4.848	4.541	9.389	130.3	5.7	9.4	145.4	6.5%
2052	1752	104	1.037	3.333	0.644	0.144	2.171	2.291	5.014	4.607	9.620	131.7	5.7	9.6	147.1	6.5%
2053	1817	105	1.075	3.456	0.650	0.147	2.202	2.324	5.181	4.673	9.854	133.1	5.7	9.9	148.7	6.6%
2054	1882	106	1.114	3.580	0.655	0.149	2.233	2.357	5.348	4.738	10.086	134.6	5.7	10.1	150.4	6.7%
2055	1949	107	1.153	3.707	0.659	0.151	2.264	2.389	5.520	4.804	10.324	136.0	5.7	10.3	152.1	6.8%
2056	2016	107	1.193	3.835	0.664	0.153	2.295	2.422	5.692	4.870	10.561	137.4	5.7	10.6	153.7	6.9%
2057	2084	108	1.233	3.964	0.669	0.155	2.326	2.455	5.867	4.935	10.802	138.9	5.7	10.8	155.4	6.9%
2058	2152	109	1.274	4.093	0.673	0.157	2.357	2.488	6.040	5.001	11.041	140.4	5.7	11.0	157.1	7.0%
2059	2220	109	1.314	4.223	0.674	0.159	2.388	2.520	6.211	5.067	11.278	141.8	5.7	11.3	158.8	7.1%
2060	2289	110	1.355	4.354	0.680	0.161	2.419	2.553	6.388	5.132	11.521	143.3	5.7	11.5	160.6	7.2%
2061	2358	111	1.395	4.485	0.684	0.163	2.450	2.586	6.565	5.198	11.763	143.3	5.7	11.8	160.8	7.3%
2062	2426	111	1.436	4.615	0.690	0.165	2.481	2.618	6.740	5.264	12.004	143.3	5.7	12.0	161.0	7.5%
2063	2495	112	1.476	4.746	0.695	0.167	2.512	2.651	6.918	5.330	12.247	143.3	5.7	12.2	161.3	7.6%
2064	2564	113	1.517	4.877	0.701	0.169	2.543	2.684	7.095	5.395	12.490	143.3	5.7	12.5	161.5	7.7%
2065	2632	114	1.558	5.006	0.707	***0.171***	2.564	2.706	7.271	5.440	12.711	143.3	5.7	12.7	161.7	7.9%
2066	2699	114	1.597	5.134	0.704	0.171	2.564	2.706	7.435	5.440	12.875	143.3	5.7	12.9	161.9	8.0%
2067	2766	113	1.637	5.261	0.702	0.171	2.564	2.706	7.600	5.440	13.040	143.3	5.7	13.0	162.1	8.0%
2068	2832	114	1.676	5.387	0.706	0.171	2.564	2.706	7.769	5.440	13.209	143.3	5.7	13.2	162.2	8.1%
2069	2898	114	1.715	5.512	0.708	0.171	2.564	2.706	7.936	5.440	13.376	143.3	5.7	13.4	162.4	8.2%
2070	2962	114	1.753	5.634	0.706	0.171	2.564	2.706	8.093	5.440	13.533	143.3	5.7	13.5	162.6	8.3%
2071	3025	113	1.790	5.754	0.701	0.171	2.564	2.706	8.245	5.440	13.685	143.3	5.7	13.7	162.7	8.4%
2072	3087	113	1.827	5.872	0.700	0.171	2.564	2.706	8.399	5.440	13.839	143.3	5.7	13.8	162.9	8.5%
2073	3147	112	1.862	5.986	0.692	0.171	2.564	2.706	8.541	5.440	13.981	143.3	5.7	14.0	163.0	8.6%
2074	3206	110	1.897	6.098	0.683	0.171	2.564	2.706	8.679	5.440	14.119	143.3	5.7	14.1	163.2	8.7%
2075	3263	109	1.931	6.207	0.674	0.171	2.564	2.706	8.812	5.440	14.252	143.3	5.7	14.3	163.3	8.7%
2076	3318	109	1.964	6.311	0.674	0.171	2.564	2.706	8.948	5.440	14.388	143.3	5.7	14.4	163.4	8.8%
2077	3371	108	1.995	6.412	0.669	0.171	2.564	2.706	9.076	5.440	14.516	143.3	5.7	14.5	163.5	8.9%
2078	3422	108	2.025	6.509	0.668	0.171	2.564	2.706	9.202	5.440	14.642	143.3	5.7	14.6	163.7	8.9%
2079	3471	108	2.054	6.602	0.667	0.171	2.564	2.706	9.323	5.440	14.763	143.3	5.7	14.8	163.8	9.0%
2080	3517	106	2.081	6.690	0.657	0.171	2.564	2.706	9.428	5.440	14.868	143.3	5.7	14.9	163.9	9.1%
2081	3561	106	2.107	6.774	0.655	0.171	2.564	2.706	9.536	5.440	14.976	143.3	5.7	15.0	164.0	9.1%
2082	3603	105	2.132	6.853	0.653	0.171	2.564	2.706	9.639	5.440	15.078	143.3	5.7	15.1	164.1	9.2%
2083	3642	103	2.155	6.928	0.639	0.171	2.564	2.706	9.722	5.440	15.162	143.3	5.7	15.2	164.2	9.2%
2084	3678	103	2.177	6.996	0.638	0.171	2.564	2.706	9.810	5.440	15.250	143.3	5.7	15.3	164.3	9.3%
2085	3712	103	2.197	7.061	0.636	0.171	2.564	2.706	9.894	5.440	15.334	143.3	5.7	15.3	164.4	9.3%
2086	3742	101	2.214	7.118	0.626	0.171	2.564	2.706	9.958	5.440	15.398	143.3	5.7	15.4	164.4	9.4%
2087	3770	101	2.231	7.171	0.626	0.171	2.564	2.706	10.028	5.440	15.468	143.3	5.7	15.5	164.5	9.4%
2088	3795	101	2.246	7.219	0.623	0.171	2.564	2.706	10.088	5.440	15.527	143.3	5.7	15.5	164.6	9.4%
2089	3817	98	2.259	7.261	0.604	0.171	2.564	2.706	10.123	5.440	15.563	143.3	5.7	15.6	164.6	9.5%
2090	3835	98	2.269	7.295	0.605	0.171	2.564	2.706	10.169	5.440	15.609	143.3	5.7	15.6	164.6	9.5%
2091	3851	97	2.279	7.325	0.601	0.171	2.564	2.706	10.205	5.440	15.645	143.3	5.7	15.6	164.7	9.5%
2092	3863	98	2.286	7.348	0.605	0.171	2.564	2.706	10.239	5.440	15.679	143.3	5.7	15.7	164.7	9.5%
2093	3873	98	2.292	7.367	0.604	0.171	2.564	2.706	10.263	5.440	15.703	143.3	5.7	15.7	164.7	9.5%
2094	3879	98	2.296	7.378	0.603	0.171	2.564	2.706	10.277	5.440	15.717	143.3	5.7	15.7	164.8	9.5%
2095	3882	97	2.297	7.384	0.603	0.171	2.564	2.706	10.284	5.440	15.724	143.3	5.7	15.7	164.8	9.5%
2096	3882	97	2.297	7.384	0.598	0.171	2.564	2.706	10.280	5.440	15.720	143.3	5.7	15.7	164.8	9.5%
2097	3879	96	2.296	7.378	0.596	0.171	2.564	2.706	10.270	5.440	15.710	143.3	5.7	15.7	164.7	9.5%
2098	3873	96	2.292	7.367	0.593	0.171	2.564	2.706	10.252	5.440	15.692	143.3	5.7	15.7	164.7	9.5%
2099	3864	97	2.287	7.350	0.597	0.171	2.564	2.706	10.234	5.440	15.674	143.3	5.7	15.7	164.7	9.5%
2100	3852	97	2.280	7.327	0.601	0.171	2.564	2.706	10.208	5.440	15.648	143.3	5.7	15.6	164.7	9.5%

APPENDIX E

Outage Projection Memo

BROWN AND CALDWELL

Technical Memorandum

Seattle Public Utilities
2007 Water System Plan Update (28901)

Date: March 7, 2006

To: Bill Wells (SPU)
Jon Shimada (SPU)
Tim Skeel (SPU)

From: Andrew Lee (Brown and Caldwell)
Corinne De Leon (Brown and Caldwell)

Copy to: File

RE: Water System Outage Projections

Water outages lead to customers being without potable water for a period of time. Water outages can be caused by both planned and unplanned activities. For example, a utility may plan to line a pipe and inform its customers that they will receive an outage for certain length of time on a specified date. On the other hand, a water pipe may experience an unplanned failure, and the repair activities necessary to fix the pipeline may result in an unplanned shutdown of water to a number of customers.

Seattle Public Utilities (SPU) is in the process of implementing a water main rehabilitation program that seeks to replace pipes at the lowest life-cycle cost to the utility and its customers (costs to customers from water outages are included in the calculation of life cycle costs – SPU calls it's cost perspective triple bottom line). The philosophy behind the program is to allow leaks/breaks to occur until it is economically (i.e., financially, socially, and environmentally) justified to replace the pipe. As the system ages, the number of unplanned failures, and therefore outages, will increase. The purpose of this technical memorandum is to evaluate the impact of SPU's water main rehabilitation program on customer water outages systemwide over the next 100 years. The technical memorandum will accomplish the following:

- Review SPU's current service level for water outages
- Summarize historical data on water outages and their causes
- Describe and present the results of a methodology for projecting the future number of customers affected by water outages greater than 4 hours in duration

SPU's Water Outage Service Level

SPU has a water outage service level target that fewer than 4 percent of retail customers will experience water outages for one or more events totaling more than 4 hours per year. Assuming that the number of customer services remains constant at 180,000, this would translate to 7200 services. While SPU is currently well within the 4 percent target, it is important to determine whether the planned replacement program will also meet the service level.

<u>Existing Outage Data</u>

SPU provided three years of water service shutoff data which included:

- Number of shutoffs
- Reason for shutoff
- Duration
- Number of customers affected
- Scheduled or unscheduled designation
- Shutoff date.

The shutoff data included shutoffs from a variety of causes such as a planned replacement of an existing water main, an unplanned repair of a broken line valve, and an unplanned repair of a broken main. Table 1 provides a summary of data on all outages.

Table 1. Summary of Data on Outages

Category	**Average Number (2002-2005)**
Total Outages per year	280 outages/year
Outages per year > 4 hours	86 outages/year
Annual average # Service connections affected by all outages > 4 hours	2061 services/year
Average # Service connections affected per outage > 4 hours	24 services/event

<u>Outages Caused by Main Leaks and Breaks</u>

Shutoff events caused by main leaks and breaks were identified and counted from the larger list by evaluating the reasons for the shutoffs. From this subset of events, main leaks and breaks causing shutoffs with durations longer than 4 hours were identified. Table 2 provides a summary of this data.

Table 2. Summary of Data on Outages Caused by Main Leaks and Breaks	
Category	**Average Number (2002-2005)**
Outages Caused by Main Leaks/Breaks	63 outages/year
Outages Caused by Main Leaks/Breaks > 4 hours in duration	15 outages/year
Annual average number of service connections affected by Outages from Mains/Leaks > 4 hours in duration	236 services/year
# Service connections affected per Outage Caused by Main Leaks/Breaks > 4 hours in duration	16 services/event

SPU has had approximately 130 main leaks/breaks per year for the past several years. Based on the data presented in Table 2, approximately 15 of those main leaks/breaks cause outages greater than 4 hours in duration each year. In other words, only 12% of main breaks/leaks lead to outages greater than 4 hours in duration. On average, approximately 16 service connections are affected by an outage caused by main breaks/leaks.

Outages Caused by Planned Water Main Replacements, Relocations, and New Installations

Shutoff events caused by planned water main replacements, relocations, or new installations were identified and counted from the larger list by evaluating the reasons for the shutoffs. From this subset of events, shutoffs with durations longer than 4 hours were identified. Table 3 provides a summary of this data.

Table 3. Summary of Data on Outages Caused by Planned Water Main Replacements, Relocations, and New Installations	
Category	**Average Number (2002-2005)**
Outages Caused by Planned Water Main Replacements, Relocations, and New Installations	71 outages/year
Outages Caused by Planned Water Main Replacements, Relocations, and New Installations > 4 hours in duration	38 outages/year
Annual average number of service connections affected by Outages from Planned Water Main Replacements > 4 hours in duration	1146 services/year
# Service connections affected per Outage Caused by Planned Water Main Replacement > 4 hours in duration	30 services / event

SPU has replaced, relocated, and/or installed approximately 18,000 ft of water main annually for the past several years. Therefore, based on the data from Table 3, for every 500 ft (2 blocks) of water main replaced in Seattle, there are typically two outages, and only one of those outages is greater than 4 hours in length. The water main replacement program has accounted for approximately 2,000 ft of water main installed. Therefore, water main replacements have accounted for approximately 4 outages greater than 4 hours per year with 120 services affected, while water main relocations and new installations have accounted for approximately 34 outages greater than 4 hours per year, affecting 1020 services.

Projection of the Future Number of Services Affected by Outages

A methodology was developed to project the future number of services affected by outages. The first step involved projecting the future number of outages from the projected number of water main failures and planned water main replacements. The second step involved projecting the number of services affected by those outages.

<u>Projected Number of Outages</u>

SPU uses a life-cycle cost model called Waverider for projecting its long-range pipe replacement and repair needs. One of the outputs of the model is a projection of the number of failures (i.e., leaks and breaks) per year for the next 100 years. As mentioned in the previous section, only 13% of main leaks/breaks lead to outages greater than 4 hours in duration. Therefore, the total number of predicted failures from Waverider was multiplied by 13% to obtain a predicted number of outages caused by unplanned failures with durations greater than 4 hours. The results are shown in Figure 1.

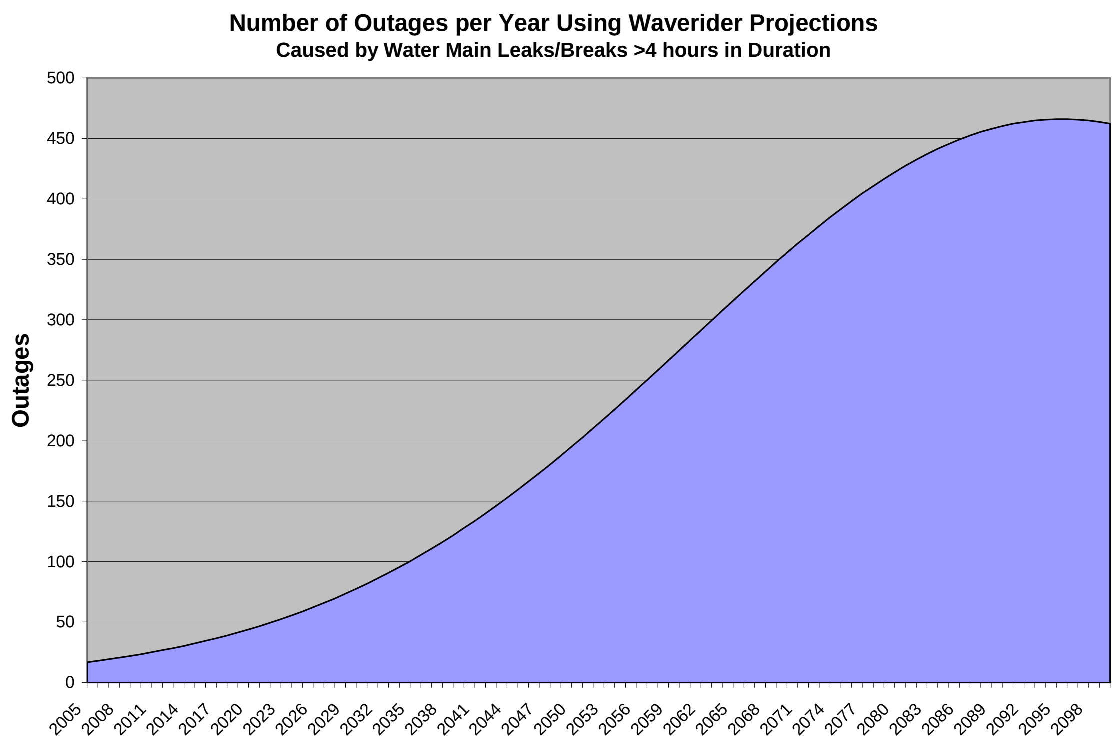

Figure 1. Projected Number of Outages Caused by Water Main Leaks/Breaks Greater than 4 Hours

Similarly, Waverider projects the lineal feet of water main to be replaced each year. As mentioned in the previous section, approximately 500 ft of water main replacement leads to one outage greater than 4 hours in duration. Therefore, the total lineal feet of predicted main replacement from Waverider was divided by 500 ft to predict the number of outages caused by main replacements with durations greater than 4 hours. The results are shown in Figure 2.

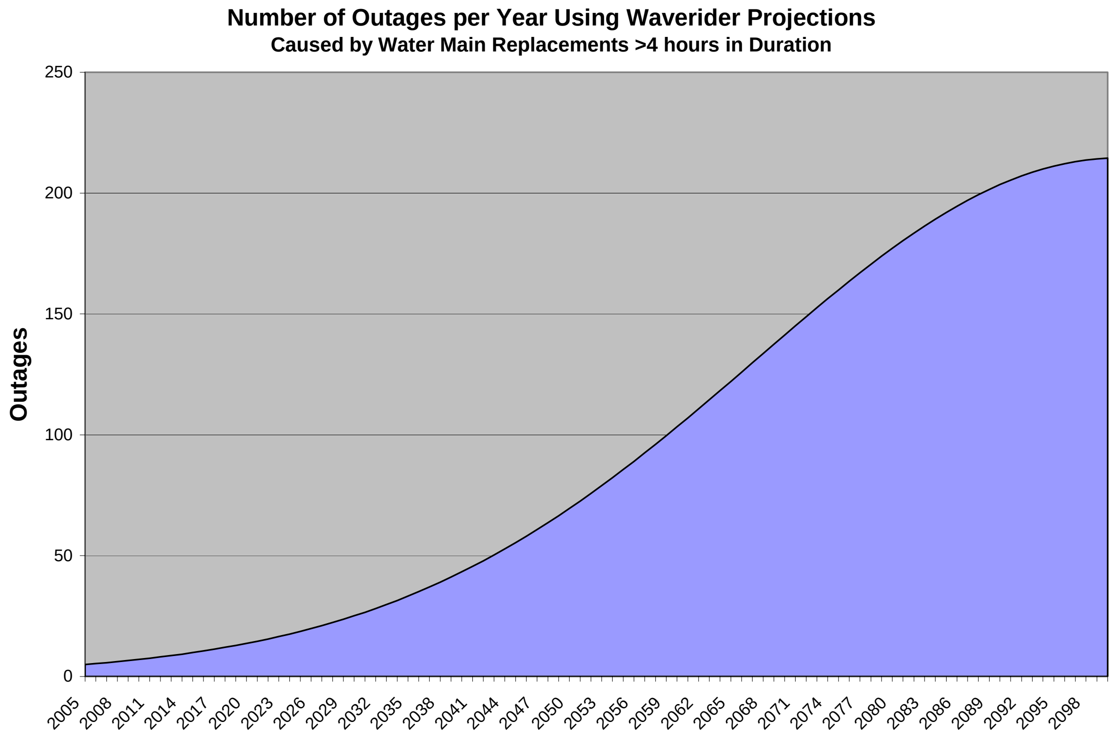

Figure 2. Projected Number of Outages Caused by Planned Water Main Replacements Greater than 4 Hours

<u>Projected Number of Services Affected</u>

As described earlier, the average number of customer service connections affected by main break outages is 16 per event. This number was multiplied by the number of outages shown in Figure 1, to predict the future number of services affected by main break outages. Similarly, the average number of services affected by water main replacements is 30 per event. This number was multiplied by the number of outages shown in Figure 2 to predict the future number of services affected by planned water main replacements.

It was assumed that outages caused by main leaks and breaks would increase over time, while outages caused by new water main installations, relocations, and other miscellaneous reasons (e.g., broken service connections, new service connections, and repairs or replacements of valves, fire hydrants, corporation stops, and water meters) would remain constant. As mentioned previously, SPU's new water main installations and relocations lead to approximately 1020 services affected by outages greater than 4 hours per year. Outages due to other miscellaneous reasons account for approximately 685 services affected by outages greater than 4 hours per year. Although there are annual fluctuations in the number of outages caused by these events, it was assumed that the number of annual outages greater than 4 hours in duration due to these causes would remain constant. Figure 2 presents the projected number of services that will be affected by outages greater than 4 hours in duration over the next 50 years.

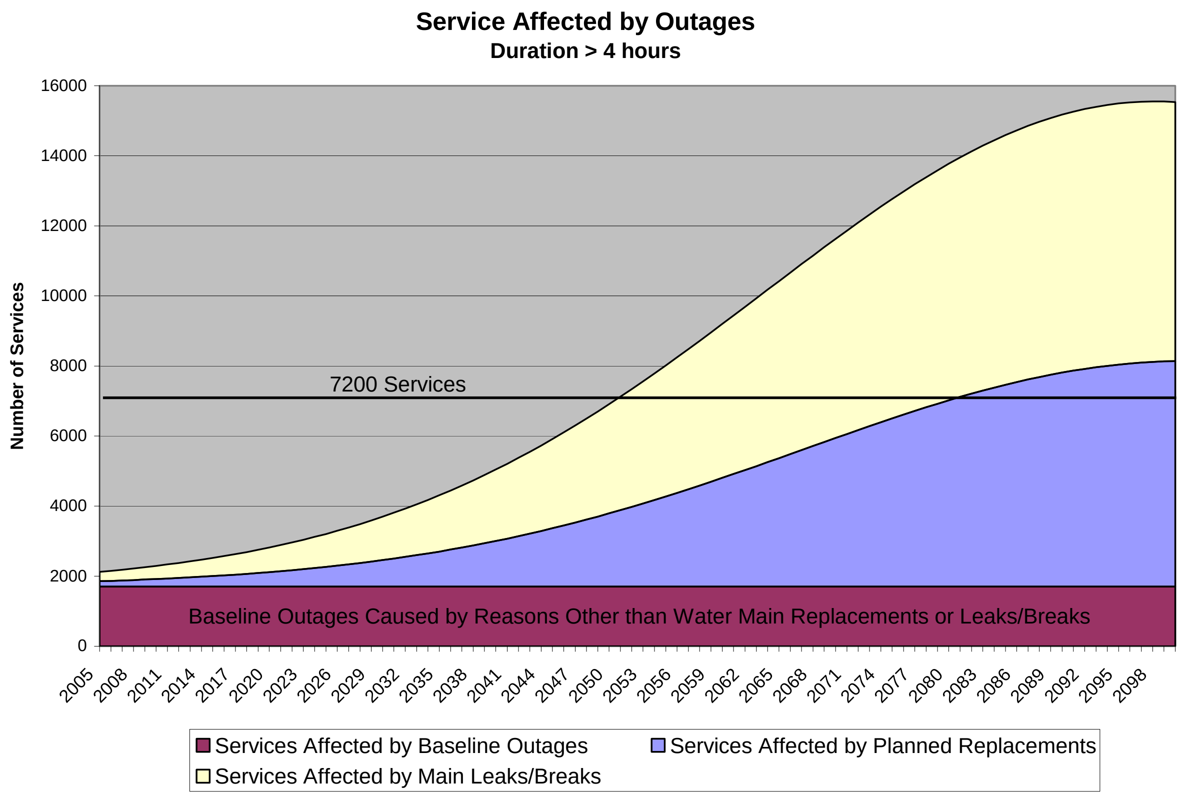

Figure 2. Projected Number of Services Affected by Outages Greater Than 4 Hours

As shown in Figure 2, SPU's current service level of no more than 7200 services affected by outages greater than 4 hours in duration will most likely be exceeded around the year 2052.

Conclusions and Recommendations

Several conclusions can be drawn from this memorandum:

- Approximately 13% of service outages exceeding 4 hours are caused by water main repairs from leaks/breaks.
- Approximately, 70% of service outages exceeding 4 hours are caused by planned pipe replacement activities. These outages are typically less bothersome to customers since they are planned.
- Based on the projection, the utility will exceed the 4% service level (7,200 services) in 2052.
- Using the current assumptions, SPU has approximately 45 years before the level of service is exceeded. This will allow time to calibrate the assumptions, gather additional information, and assess needed changes.
- Over time, strategies to reduce the number of customers affected by outages greater than 4 hours can be considered and may include:
    - Additional system valves to reduce the number of customers impacted by a shutoff
    - Use of temporary lines during planned events
    - Reducing the duration and/or number of services impacted by shut-offs for planned events

    - Throttling valves instead of shutting them completely off to allow some water service during repairs.
- SPU can also consider adopting a service level that distinguishes between planned and unplanned outages greater than 4 hours in duration